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SCIENCE & TECHNOLOGY

JAPAN

CONTENTS

International Cooperation, Exchange in Science and Technology

91FE0388A Tokyo PROMETHEUS in Japanese Nov-Dec 90 pp 8-9

[Article by the International Cooperation Division, Science and Technology Agency (STA)]

[Text] As Japan has become more internationalized, cooperation and exchanges have become an important policy expected of the government. The Japanese government is promoting cooperative activities--such as exchange of information, exchange of researchers and joint research projects--based on agreements on scientific and technical cooperation, cooperation on the peaceful use of atomic energy; and other projects in energy development, such as atomic energy, natural resources development, space development, oceanic development, life sciences, environmental protection, farming, forestry and fishery.

Some typical large research projects being promoted through international cooperation are the Human Frontier Science Project [HFSP], the International Thermonuclear Energy Reactor Project [ITER], and the Space Station Project.

To promote international exchanges of researchers, the Fellowship Program by STA, Special Foreign Researcher Program by the Japan Society for the Promotion of Science, and the Research Exchange Program by MITI's Agency of Industrial Science and Technology were initiated in 1988. Based on these programs, about 300 researchers were received from over 30 countries in 1989.

Table 1. Science & Technology-Related International Exchange Programs

Bilateral Cooperation

(4)

to

(12)

Multinational Cooperation

(1)

(2)

(3)

Science & Technology, General
(See Footnote 1)

(13)
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	(58) (ICSTD)
	(59)
	(60) (ESCAP)
	(61) (IAEA)
	(62)
	(63) (IDNDR)
(57) OECD	(64) (CSTP)
	(65) (IEA)
	(66) (NEA)

(67)
(68)

Atomic Energy-Related

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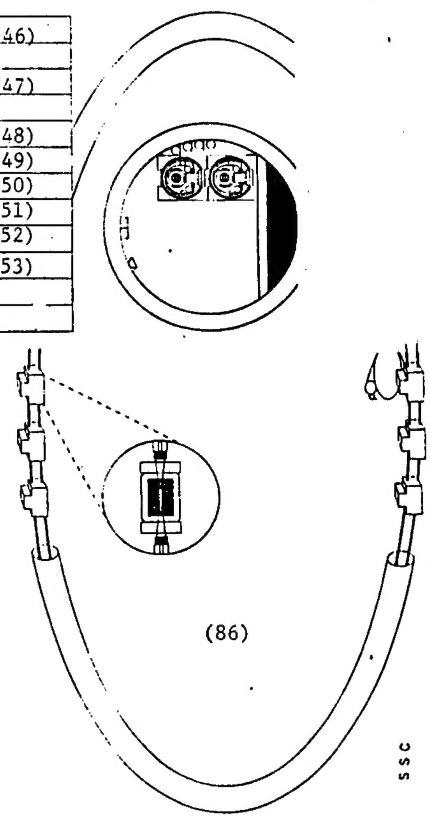
(79)

Space-Related

(80)
(81)
(82)

Miscellaneous

(83)
(84)
(85)



[Key on following page]

Key:

1. Multinational cooperative agreements
2. Cooperation through international organizations
3. Regional cooperation
4. S&T, General
5. Agreements on S&T cooperation
6. Arrangements on S&T cooperation
7. Miscellaneous
8. Atomic energy related
9. Agreements on atomic energy
10. Official exchange notes
11. Space related
12. Others
13. Fourteen agreements on S&T cooperation, each with 14 nations as signatories
14. Agreement on S&T cooperation between Japan and the USSR (October 1973)
15. Agreement on S&T cooperation between Japan and France (July 1974)
16. Agreement on S&T cooperation between Japan and West Germany (October 1974)
17. Agreement on S&T cooperation between Japan and Poland (November 1978)
18. Agreement on S&T cooperation between Japan and the People's Republic of China (May 1980)
19. Agreement on S&T cooperation between Japan and Australia (November 1980)
20. Agreement on S&T cooperation between Japan and Indonesia (April 1981)
21. Agreement on S&T cooperation between Japan and Yugoslavia (February 1982)
22. Agreement on S&T cooperation between Japan and Berlin (June 1985)
23. Agreement on S&T cooperation between Japan and India (November 1985)
24. Agreement on S&T cooperation between Japan and the Republic of Korea (December 1985)
25. Agreement on S&T cooperation between Japan and Canada (May 1986)
26. Agreement on S&T cooperation between Japan and the United States (June 1988)
27. Agreement on S&T cooperation between Japan and Italy (October 1988)
28. Five arrangements, each with 5 nations as signatories
29. Arrangement on S&T cooperation between Japan and Romania (April 1975)
30. Arrangement on S&T cooperation between Japan and Bulgaria (March 1978)
31. Arrangement on S&T cooperation between Japan and Czechoslovakia (November 1978)
32. Arrangement on S&T cooperation between Japan and Hungary (May 1979)
33. Arrangement on exchange of researchers between Japan and the USSR (November 1987)
34. Others, 11 conferences
35. Japan-U.S. Committee on Scientific Cooperation (June 1961)
36. Japan-Korea Periodic Conference of Cabinet Members (August 1967)
37. Japan-Korea Conference of Science and Technology Ministers (September 1968)
38. Japan-European Community [EC] High-Level Council (May 1974)
39. Japan-Sweden Trade and Economy Council (September 1976)
40. Japan-China Conference of Cabinet Members (December 1980)

41. Japan-Norway Trade and Economy Council (November 1981)
42. Japan-EC Conference of Cabinet Members (May 1984)
43. Japan-Finland Trade and Economy Council (November 1984)
44. Japan-Finland Meeting for Scientific & Technological Cooperation (November 1987)
45. Japan-U.K. Working-Level Meeting for Scientific & Technological Cooperation (July 1989)
46. S&T-related (See Footnote 2)
47. August 1985
48. January 1982
49. September 1986
50. July 1985
51. October 1986
52. November 1985
53. April 1986
54. Summit meeting
55. Agreement on Space Base Cooperation (September 1988) (See Footnote 3)
56. International Space Year (ISY)
57. Organization for Economic Cooperation and Development (OECD)
58. Intergovernmental Committee on S&T Development (ICSTD)
59. United Nations Conference on New and Renewable Energy Sources
60. Economic and Social Commission for Asia and the Pacific (ESCAP)
61. International Atomic Energy Agency (IAEA)
62. Committee on Peaceful Uses of Outer Space
63. International Decade for the Prevention of Disasters (IDNDR) (1990) and others
64. Commission on Science & Technology Policy (CSTP)
65. International Energy Agency (IEA)
66. Nuclear Energy Agency (NEA) and others
67. Association for Scientific Cooperation in Asia
68. Japan-ASEAN [Association of South-East Asian Nations] Scientific and Technological Cooperation
69. Six agreements on atomic energy each with 6 nations as signatories
70. Agreement on atomic energy between Japan and the United Kingdom (October 1968)
71. Agreement on atomic energy between Japan and France (September 1972)
72. Agreement on atomic energy between Japan and Canada (September 1980)
73. Agreement on atomic energy between Japan and Australia (August 1982)
74. Agreement on atomic energy between Japan and China (July 1986)
75. Agreement on atomic energy between Japan and the United States (July 1988)
76. Three official notes on exchange programs each with 3 nations as signatories
77. Japan-Germany official notes on exchanges for the peaceful use of atomic energy (March 1959)
78. Japan-Sweden official notes on exchanges for peaceful uses (April 1973)
79. Japan-Italy official notes on exchanges for peaceful uses (November 1973)
80. Japan-U.S. official notes on exchanges on space-related programs (July 1969)

81. Japan-ESA [European Space Agency] official notes on exchanges (December 1972)
82. Japan-U.S. Permanent Space Staff Liaison Group (SSLG) (July 1979)
83. Japan-U.S. Conference on the Development and Utilization of Natural Resources (January 1964)
84. Japan-U.S. agreement on energy cooperation (February 1990)
85. Japan-EC cooperation agreement on nuclear fusion (February 1989)
86. Artist's conception of the SSC [superconducting super collider]

Footnote 1: Sometimes, cooperative programs in atomic energy and space research are included in general agreements on science & technology.

Footnote 2: "Science & technology-related" lists the dates at which science & technology were adopted as agenda items for the first time.

Footnote 3: The date in parentheses is the date at which the agreement was signed. Preparations to activate the agreement are in progress.

Developments in Polymer Research

CFRP Environmental Deterioration Characteristics: Deterioration in Electron Beam, γ-Ray, and Thermal Cycle

916C1038A Tokyo KOBUNSHI FURONTIA in Japanese 15 Feb 91 pp 66-73

[Article by N. Nakano and S. Hasegawa: "Guide for Optimum Design of Advanced Materials Used for Hazardous Environments"]

[Text] 1. Introduction

Because of their excellent performance, advanced composite materials (CFRP) are being sought for use under hazardous environments, such as high and low temperature, high and low pressure, ultrahigh speed impact, and heavy irradiation. One of the ultimate objectives of material research is to design and manufacture materials able to meet required performance yet retain safety under such environments over their total predicted life span. An important problem in this is to clarify the strength and properties of materials used and to establish environmental hazard resistance evaluation technology. Space is one of the hazardous environments. The space environment features a high vacuum, great temperature differences, intense ultraviolet light, high energy radiation, high speed radical particles, and zero gravity. This article describes results of a study on deterioration behavior of CFRPs resulting from various environmental factors, such as electron beams, γ-rays, and thermal cycle, in an assumed space environment; it was carried out in order to develop a space-environment simulation apparatus.

2. Deterioration Characteristics of CFRPs Resulting From Various Environmental Factors

The matrix of CFRPs is a bisphenol epoxy resin with a glass dislocation temperature (Tg) of 143°C, a specific gravity of 1.211, and a bending strength of 142 MPa. The carbon fiber used is Toho Rayon Co.'s T-300 (high strength), unidirectionally reinforced, with a fiber packing ratio of 60 vol-%. It is formed by heating and pressurizing at 80°C for two hours, with after-cure carried out at 120°C for four hours.

2.1 Deterioration Characteristic Caused by Electron Beam Exposure[1]

The effects of temperature under electron beam irradiation was studied. Bending strength showed a constant value at 50°C, independent of dosage. At 150°C, bending strength decreases as dosage increases. At 250°C, decomposition and deterioration occur--such as promoted oxidation and cutting of molecular chains, which are added by temperature application, thereby presumably causing a synergetic effect that promotes deterioration. The result of changes in bending strength when the dosage ratio is varied shows that deterioration becomes remarkable with the same dosage when the dosage ratio is low. Sequential test results of electron beams and thermal impact were then studied. When thermal impact was provided after electron beam irradiation, recovered bending strength resulting from thermal impact could be observed. This seems to result from recoupling of radicals generated by electron beam irradiation because of a temperature-caused annealing effect. With materials that showed virtually no change in bending strength from only thermal impact, a decrease in bending strength could be observed when they underwent electron beam irradiation after thermal impact. Figure 1 presents changes in temperature of the specimen and changes with time in gases generated when an electron beam is irradiated on a CFRP under a vacuum. Electron beam irradiation for five minutes was repeated after each five-minute stop. Temperature of the specimen rises with electron beam irradiation and falls when it is stopped. Individual mass number shows similar behavior, implying that this activity occurs from electron beam irradiation. The effect of electron beam irradiation under a vacuum was then studied. At 150°C, virtually no difference in bending strength was observed, whether there was electron beam irradiation for a short exposure or there was no irradiation; for long exposure, however, a decrease in bending strength due to electron beam irradiation can be observed. At 250°C, a tendency similar to that of 150°C is seen. It has been made clear that in simple exposure under a thermal vacuum, the weight of a CFRP undergoes virtually no change; however, when exposure conditions include electron beam irradiation, its weight remarkably decreases with exposure time (an increase in absorption dosage). Electron beam irradiation causes the number of types of discharged gas components to increase remarkably. Above all, many of them are low-grade alcohol components, which seem to be products of decomposition of unconverted reactive diluents. Aromatic hydroxy compounds, including phenol and cresol, have been detected, and are considered to be products of decomposition of the CFRP's matrix resin. Under simple exposure under a thermal vacuum not accompanying electron beam irradiation, no aromatic hydroxy compounds, including phenol and cresol, could be detected. These results imply that a decrease in weight of a CFRP caused by electron beam irradiation under a thermal vacuum is mainly attributable to decomposition of the matrix resin.

2.2 Deterioration Characteristics Caused by γ-Ray Irradiation[2-4]

For a CFRP specimen not heat-treated, one heat-treated at 150°C for two hours, and one heat-treated at 200°C for one hour, a change in thermal mechanical characteristics was measured by a dynamic thermomechanical analyzer (DMA) and the behavior in generation of oxides was measured by infrared absorption spectra after irradiation by γ-rays of 200 to 1,000 Mrad.

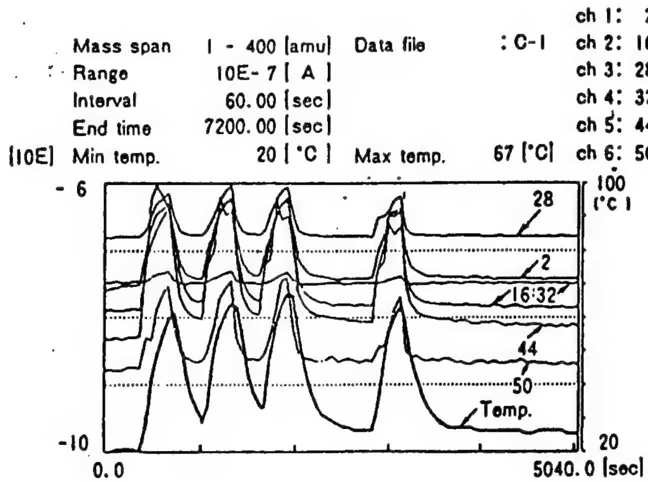


Figure 1. Changes in Temperature and Mass Number of CFRP Caused by Electron Beam Irradiation (in a vacuum)

Figure 2 presents a change in peak temperature of tan δ. With both the first and the second peak, peak temperature shifts to the low temperature side as exposure increases. Figure 3 presents the relationship between exposure and tensile elastic modulus at low and high temperatures. The high temperature elastic modulus tends to decrease as exposure increases, while the low temperature elastic modulus shows a complex tendency of maximum and minimum with exposure. A change in epoxy resin irradiated by γ-ray shows a similar tendency to that of a CFRP, thereby implying that a change in a CFRP tends to depend on a change in the matrix. Such a complex tendency as above seems to be the result of two actions caused by γ-ray irradiation. γ-ray irradiation causes molecular chains to be cut and bridge density to increase. On the other hand, γ-ray irradiation causes a new bridge to be generated to increase bridge density. It seems that these become entangled with one another in a complex manner to show such results. In other words, γ-ray irradiation causes the specimen's bridge that exists from the beginning to reduce and unbridged areas to be bridged, and the total bridge density shows a complex change through rebridging when cut bridged areas are exposed.

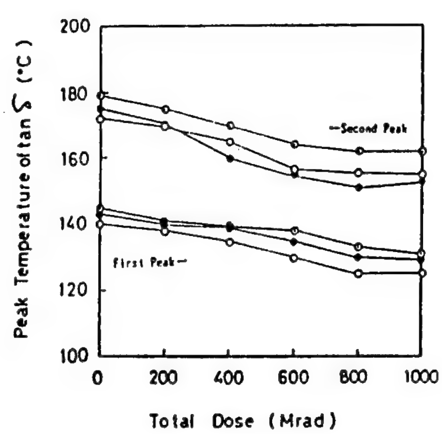


Figure 2. Peak Temperature of tan δ of γ-Ray Irradiated CFRP

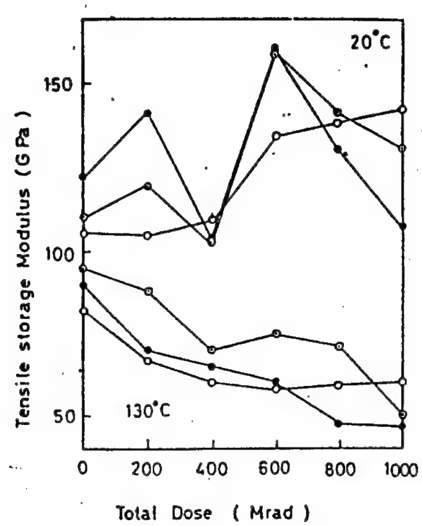


Figure 3. Changes in Low Temperature and High Temperature Elastic Moduli Caused by γ-Ray Irradiation

The following is a description of measurement results by FT-IR of the behavior in generation of oxides of a γ-ray irradiated epoxy specimen. A comparison of the original specimen with the γ-ray irradiated one finds that large absorption in the neighborhood of 3,400 cm^{-1}, resulting from γ-ray irradiation, can be observed and that absorption begins to appear in the neighborhood of 1,700 cm^{-1}. When difference spectra are considered, spectra for the γ-ray irradiated specimen with a peak at 3,224 cm^{-1} (OOH, hydroperoxide, 1,712 cm^{-1} (C=O, ketone), and 1,658 cm^{-1} (CO-OH, carboxylic acid) can be obtained. As shown in Figure 4, they increase with exposure, which implies that γ-ray irradiation helps promote oxidation reaction.

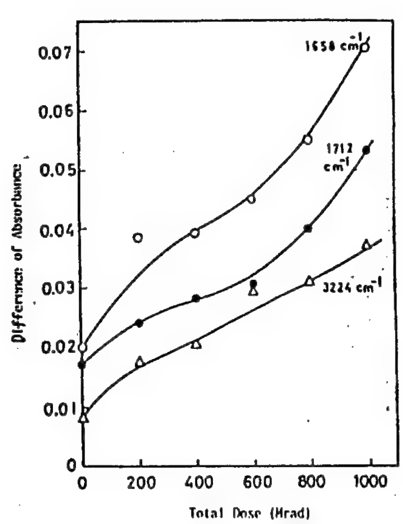


Figure 4. Changes in Difference Spectra of Infrared Absorption Caused by γ-Ray Irradiation

2.3 Deterioration Characteristics Caused by Thermocycle[5-10]

First, a thermal aging test was conducted to study thermal influence. In thermal aging of a CFRP at 150°C, virtually no change was caused in statistical mechanical characteristics, but a remarkable change was shown in thermomechanical characteristics measured using a DMA. Figure 5 presents a change in tan δ of a thermal aging CFRP. Peak values on the low temperature side of tan δ show a remarkable decrease with time, while peak temperature shifts to the high temperature side with thermal aging time. The tensile storage elastic modulus tends to increase early and to decrease later on both the high and low temperature sides.

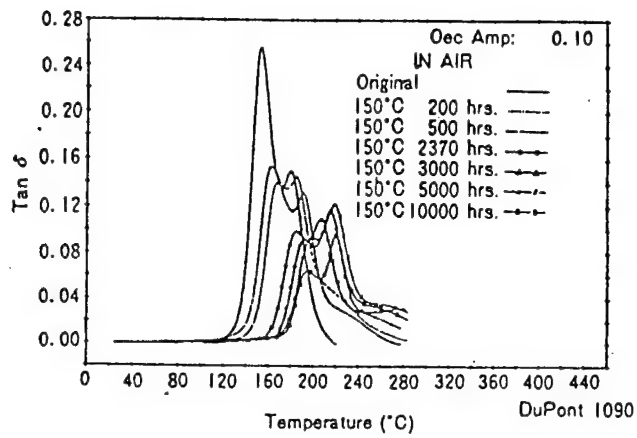


Figure 5. Tan δ of Thermal Aging CFRP

Second, the influence of thermal cycle on deterioration of a CFRP was studied using a test-manufactured thermocycle fatigue tester. The tester is designed to be loaded up to 10 tons and a temperature range can be arbitrarily set with cycle time in a range between -50° and 250°C.

Deterioration behavior was studied by varying the temperature range, load, and number of cycles (at a rate of 90 minutes per cycle) under bending load in a temperature range between -50° and 250°C. Figure 6 presents a change in damping of a CFRP that has undergone thermal fatigue of 10 cycles in a temperature range between -50° to 100°C. The original specimen shows a sharp peak in the neighborhood of 160°C and a shoulder between 180° and 190°C. This peak is called a first peak. As the load increases, the damping value of the first peak decreases. With a load of not more than about 550 MPa, peak temperature shifts to the low temperature side. As damping decreases, the area that was a shoulder in the original specimen appears as a peak, which is called a second peak. The damping value of the second peak is constant, irrespective of an increase in load. With a load exceeding 700 MPa, damping of the first peak becomes almost constant, while another peak appears between the first and the second peak, which is called a third peak. Figure 7 presents a change in damping when a CFRP undergoes thermocyclic fatigue with a load of 549 MPa in a temperature range between -50° to 100°C. With an increase in number of cycles, the damping value of

the first peak rapidly decreases. Until it reaches 10 cycles, peak temperature shifts slightly to the low temperature side, and it reversely shifts to the high temperature side when the cycle grows larger. The second peak, whose damping value is constant irrespective of the number of cycles, appears as damping decreases. When it reaches 20 or more cycles, the third peak appears. Figure 8 presents a change in damping when 10 thermocycles at a load of 206 MPa was given in a temperature range starting at -50°C. As the temperature range increases, the damping value of the first peak decreases. Until temperature reaches 180°C, the peak temperature shifts to the low temperature side, and it shifts to the high temperature side as the temperature range grows larger. The second peak, whose damping value is constant irrespective of a temperature range, appears as damping decreases. As fatigue conditions become severe, the number of peaks increases. Also, the first peak shows a remarkable decrease due to fatigue.

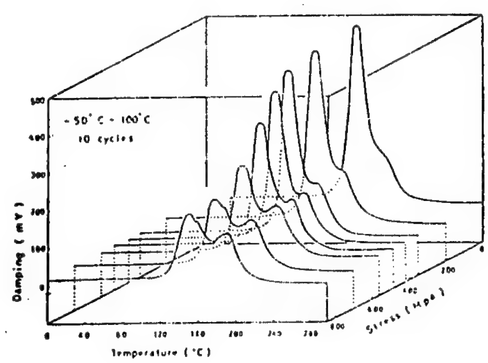


Figure 6. Changes in Damping of CFRP Caused by Thermocyclic Fatigue (-50° to 100°C, 10 cycles)

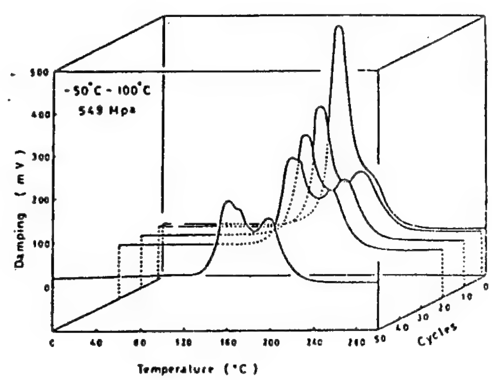


Figure 7. Changes in Damping of CFRP Caused by Thermocyclic Fatigue (-50° to 100°C, 549 MPa)

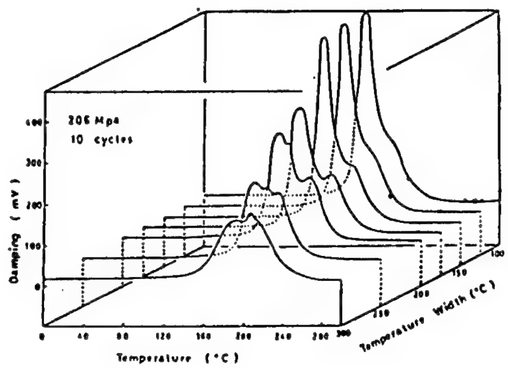


Figure 8. Changes in Damping of CFRP Caused by Thermoxylic Fatigue (206 MPa, 10 cycles)

Third, a change in bending strength of a CFRP that has undergone thermocyclic fatigue was measured. Figure 9 presents the change in bending strength retention with a temperature range between -50° and 150°C. Bending strength retention decreases as load increases. The greater the number of cycles, the smaller the load at which bending strength retention begins to decrease. With a large load, bending strength retention remarkably decreases with the number of cycles in the early stage, with a minor change in the later stage. With a small load, it does not decrease in the early stage, but does so as the number of cycles increases in the later stage. Figure 10 presents a similar change with a temperature range between -50° and 50°C. With a small load, strength retention does not decrease, but monotonously does so when it grows larger. The greater the number of cycles, the smaller the load at which strength retention begins to decrease. Under this condition, bending strength retention virtually does not decrease when the number of cycles is small, and begins to decrease as the number of cycles increases. In a range of the above conditions, the wider the temperature range, the more remarkable the decrease in bending strength retention. The tendency toward a change in the first peak value of damping with a change in fatigue conditions was similar to that of bending strength retention.

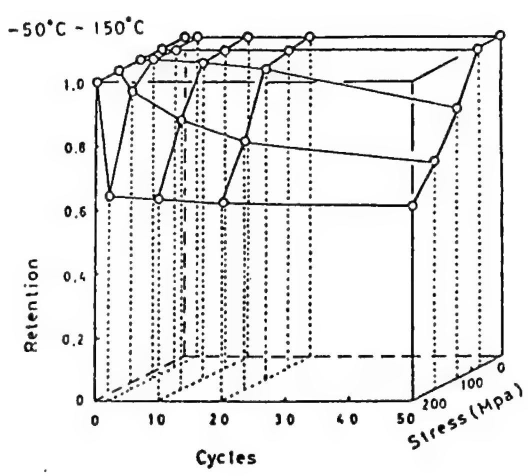


Figure 9. Changes in Bending Strength Retention Caused by CFRP's Thermo-cyclic Fatigue (temperature range, -50° to 150°C)

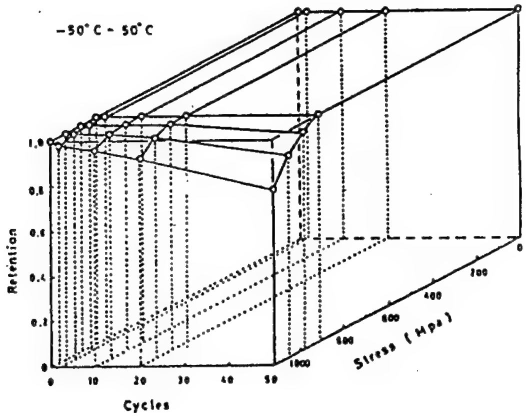


Figure 10. Changes in Bending Strength Retention Caused by CFRP's Thermocyclic Fatigue (temperature range, -50° to 50°C)

A change in damping caused by thermocyclic fatigue implies that the matrix area of a CFRP can be divided into three: an ordinary matrix area, an area of interface bonded with a filler, and an area with a certain layer surrounding the filler. The matrix area existing in the shape of a layer around the filler can be observed in a photograph taken by scanning electron microscope of a fractured filler in an area in good bonding condition, implying that the presence of this area is necessary to some extent for retaining CFRP strength.

Figure 11 presents the relationship between δ, a ratio of the matrix layer surrounding the filler to the filler, and filler volume packing ratio V_f and bending strength, respectively. As shown in Figure 12, sectional filler packing patterns can be expressed by a square pattern and a diamond pattern. The actual material seems to be a mixture of both patterns. Let the filler's radius be r, and the thickness of the matrix layer surrounding the filler can be shown as δ r. V_f of the square pattern can be expressed by the lower equation in the drawing and that of the diamond pattern by the upper equation. Figure 11 illustrates both equations, and it is considered that an actual CFRP exists between these two curves. As for the relationship between δ and bending strength, an experiment confirmed, as shown in the drawing, that bending strength reached maximum where $\delta \fallingdotseq 0.15$ ($V_f \fallingdotseq 60$ percent). This implies that until V_f remains about 60 percent, strength increases as V_f increases, and after V_f exceeds 60 percent, the matrix layer surrounding the filler thins and strength decreases. Figure 13 presents a change in damping caused by thermocyclic fatigue shown in terms of a model. The solid lines are actual damping curves, which can be expressed as synthetic curves of damping based on the three areas. The broken lines show curves based on the ordinary matrix area; those shown by a dashed line and a two-dot chain line are curves based on the interface area and the area surrounding the filler, respectively. The curves in (a) show damping of the original specimen, and progress in fatigue is seen as they shift to (b) to (c). As fatigue progresses, damping based on the ordinary matrix area decreases, while damping in the other two areas undergoes virtually no

change. Therefore, as fatigue progresses, a second and a third peak will appear. Deterioration in a CFRP caused by thermocycle is generated by deterioration in the ordinary matrix resin, appearing as a decrease in the first peak. A change in damping resulting from deterioration caused by thermocycle of an epoxy resin causes only one peak to appear, which remarkably decreases due to deterioration. Also, the tendency toward a decrease in bending strength caused by deterioration is similar to that of the decrease in the first peak of damping, which also implies that deterioration in a CFRP is caused by deterioration in the ordinary matrix area, and it is considered that the presence of the other two areas plays a major role in retaining durability and strength against fatigue of a CFRP.

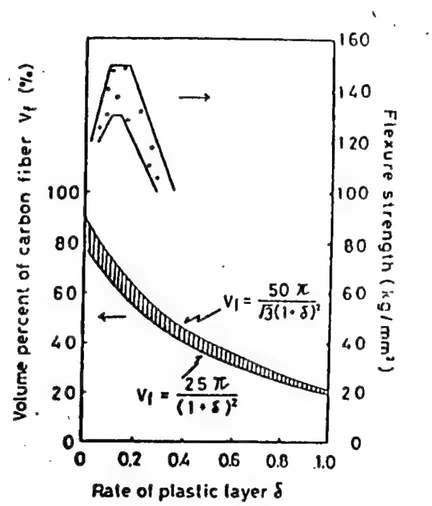


Figure 11. Relationship Among Thickness, V_f and Bending Strength of CFRP's Matrix Layer

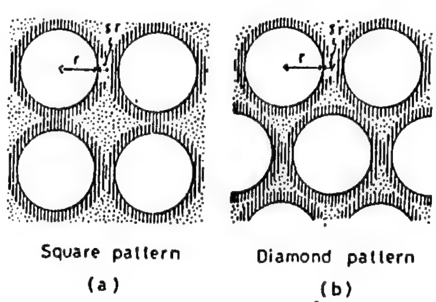


Figure 12. Packing Patterns of CFRP's Filler

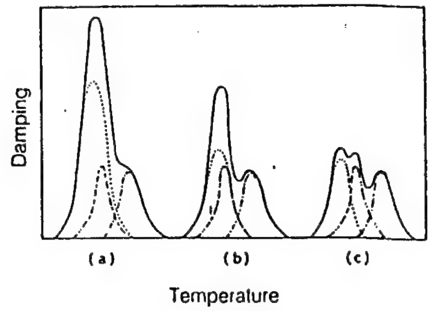


Figure 13. Model Curves of Changes in Damping Caused by CFRP's Thermocyclic Fatigue

3. Deterioration Characteristics Measured by Space Environment Simulator

A study was made of deterioration characteristics caused by ultraviolet rays and far ultraviolet exposure in addition to the above environments.[11] Based on systematized data on the deterioration tendency obtained by deterioration tests of their respective environmental factors, a tester of environments comprising various factors under space environment was developed, i.e., a space environment simulator.[12,13] The apparatus is capable of thermocycling and irradiating far ultraviolet rays and electron beams under a high vacuum and stress load conditions. It is also capable of degasification analysis during environmental deterioration tests and of in-situ measurement of mechanical characteristics of materials.

Tests using the apparatus have been carried out on thermocyclic environmental evaluation, electron beam exposure, and far ultraviolet exposure in a high vacuum. The following is a description of thermal aging deterioration characteristics, which showed a remarkable difference in deterioration tendency from that in atmosphere.

Thermal aging was conducted in a vacuum using this apparatus, and changes in CFRP's bending characteristics and thermomechanical characteristics by DMA were studied. Figure 14 presents changes in the tensile storage elastic modulus of a CFRP under thermal aging in a vacuum and tan δ. At low temperature (65°C), the tensile storage elastic modulus undergoes a minor change, but at high temperature (150°C), it shows a major change, increasing in the early stage and decreasing after a long time (3,400 hours). The temperature at which the elastic modulus rapidly decreases shifts to the high temperature side as thermal aging time increases. The tendency toward change in atmosphere is similar to that in a vacuum, but the latter is remarkable. A change in tan δ of a vacuum thermal aging CFRP involves two peaks at 65°C, similar to the case in atmosphere, with peak temperature shifting to the high temperature side. At 150°C, only one peak appears, and peak temperature shifts more largely to the high temperature side, showing a remarkable change.

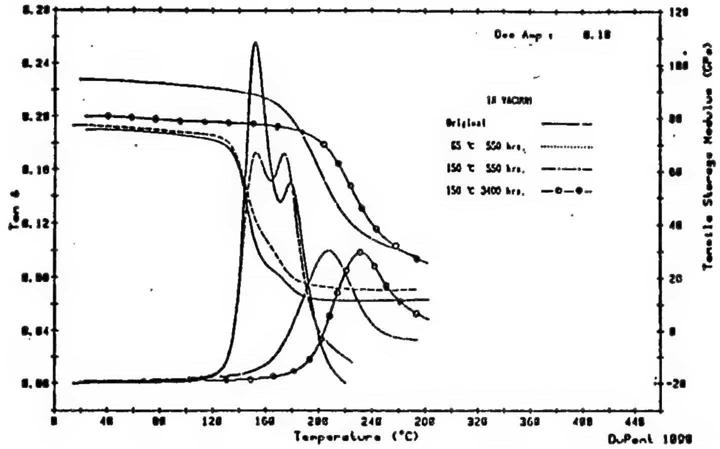


Figure 14. Tensile Elastic Modulus and tan δ of Vacuum Thermal Aging CFRP

4. Conclusion

Advanced composite materials led by a CFRP are increasingly likely in the future to find applications because of their characteristics under hazardous environments, and securing safety is becoming an important problem. To cope with this, correct material evaluation and exact life prediction will be more important. The development of durability test technology by a tester that simulates environments, such as this apparatus, can be expected to improve evaluation performance.

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Carbon From Polyimide Polymers

916C1038B Tokyo KOBUNSHI FURONTIA in Japanese 15 Feb 91 pp 82-88

[Article by H. Hatori, Y. Yamada, and M. Shiraishi, National Research Institute for Pollution and Resources: "Creation of New Carbon From Polymers"]

[Text] 1. Introduction

Carbon materials have superior properties in terms of heat resistance and conductivity, and are currently used in various industrial fields, in particular in the field of electrodes for use in manufacturing steel. New carbon material is obtained by substantially improving disadvantages of conventional carbon materials or by providing them with totally new functional characteristics. To create such materials requires technology for precisely molding a bulky material while controlling the carbon microstructure through selective design of materials and the molding process. Representative of a new carbon material is a carbon fiber that is establishing a firm position as a fiber reinforcing filler for composite materials.

It has been reported in recent years that heat resistant polymers--such as polyimide,[1,2] polyoxadiazol,[3] and polyparaphenylenevinylene[4] (PPV)--contract as solid phase carbon, but retain their shape and provide graphite film of high crystal character. It has been accepted that polymers such as a phenol resin, which are carbonized in a solid phase, are of refractory graphitization, which disables a graphite structure from developing in general, even under high temperature treatment. It has been made clear that, with PPV films, orientation by drawing enables graphitization quality to improve, and it is considered that the molecular orientation as well as the molecular structure of a polymer material are important influences on development of the graphite structure. However, the process of thermal decomposition, in which a polymer changes into carbon, is difficult to understand, and thus much remains unknown about the relationship between constructions of polymers and carbon.

The authors are considering the relationship between carbon and the high-order structure of poly (4,4'-oxydiphenylenepyromellitimide, which is a so-called kapton-type polyimide (PI). The following are descriptions of PI and a graphite composite fiber produced by utilizing the former's characteristics.

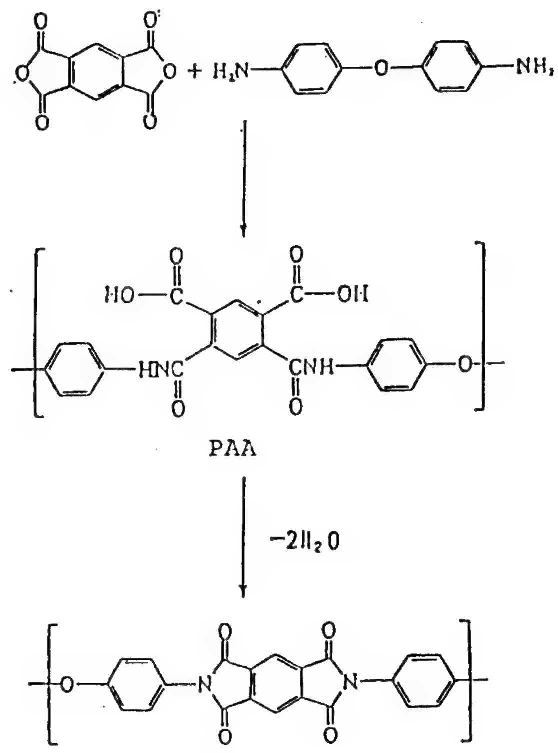

Figure 1

2. In-Plane Orientation and Graphitization Quality of PI Film[5]

An in-plane oriented film and an isotropic film were produced by various methods and their graphitization qualities were compared.

The in-plane oriented film and non-oriented film were prepared according to the method by Russell, et al.[6] In other words, when films obtained by casting a polyamic acid (PAA) solution were made into imide at 200°C, some of the films were heat treated as they were on the glass substrate to obtain an oriented film (200-on), and the rest were treated after being separated from the glass substrate to produce a non-oriented film (200-off). Also, a non-oriented film (Ac_2O-off) was obtained by producing imide by acetic anhydride-pyridine. Furthermore, PAA films produced by vapor deposition polymerization[7] were made into imide on the glass substrate at 200° and 350°C (Vac-200 and Vac-350).

For carbonization treatment, each sample was heated to 800°C at a rate of 5°C/min in argon draft and retained for one hour. This caused a weight reduction of about 45 percent with each specimen, followed by a linear contraction of 20 percent, providing a carbonaceous film with black gloss retaining the original shape.

Table 1 presents spacings (inter-graphite layer distance) of specimens obtained by heat treating these films at 2,800°C for one hour. From this

table, it is found that only 200-off and Ac_2O-off are of refractory graphitization quality and that other specimens have good graphitization quality (free graphitization quality) similar to kapton. TEM observation also shows a clear difference between constructions of the two (Figure 2). From the above results, it is clear that postsintering graphite structure largely depends on the in-plane orientation of PI.

Table 1

	Interlayer spacing (Å)
200-on	3.359
200-off	3.43
Ac_2O-off	3.46
Vac-200	3.359
Vac-350	3.358
Kapton	3.358

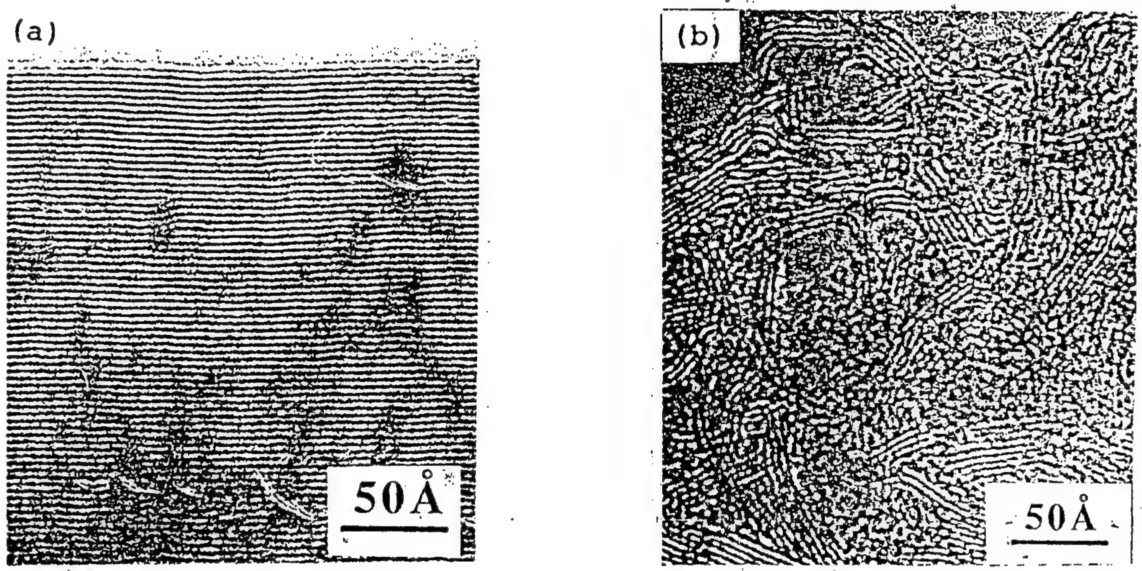

Figure 2. TEM Micrographs of (a) 200-on and (b) Ac_2O-off Heat-Treated at 2,800°C

3. Carbonization Initial Reaction Mechanism of Kapton Film[8]

With respect to the thermal decomposition reaction mechanism of a kapton film, many researchers have already carried out studies by gas analysis and elemental analysis.[1,9] Figure 3 presents measuring results by the authors on TG and gas analysis. It is found that CO and CO_2 deposit along with a heavy decrease in weight at between 500° and 600°C.

Furthermore, the authors tried to assume affected areas by thermal reaction by reducing the molecular weight through hydrolysis of the initial products

in PI thermal decomposition and by GC-MS analysis. In other words, a specimen of 100-H commercial kapton was heat treated at each treatment temperature for 30 minutes, and a residual imide group was then hydrolyzed to reduce molecular weight. Ethyl acetate benzene soluble components were separated into acid components and basic ones by extraction; qualitative and quantitative analyses were made with each of them.

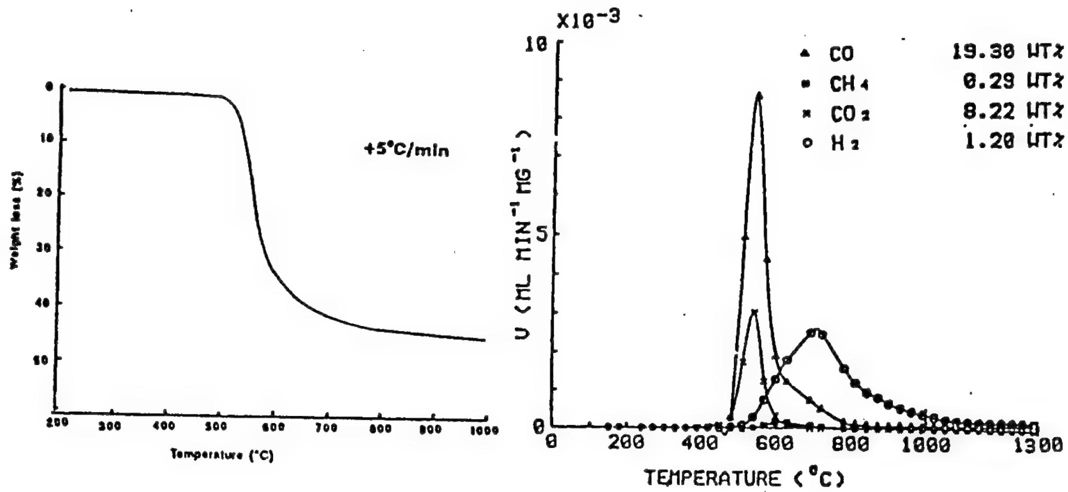

Figure 3. (a) TGA, (b) Analysis of Gaseous Products

The total extraction amount decreased as heat treatment temperature increased, until at last nothing could be obtained at 560°C and above. Phthalic acid (PA) and compounds shown in Figure 5 were identified by GC-MS. As shown in Figure 4, phthalic acid is considered to be obtained through hydrogen trapping of radicals generated by decomposition of pyromellitimide position. Amines in Figure 5 are derived from the diphenylether position, and the dibenzofuran skeleton seems to be generated by dehydrogenation of the ortho position of ether oxygen.

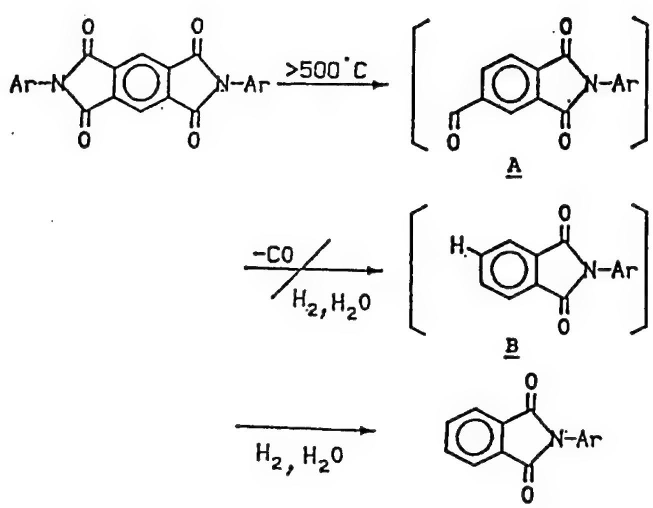

Figure 4

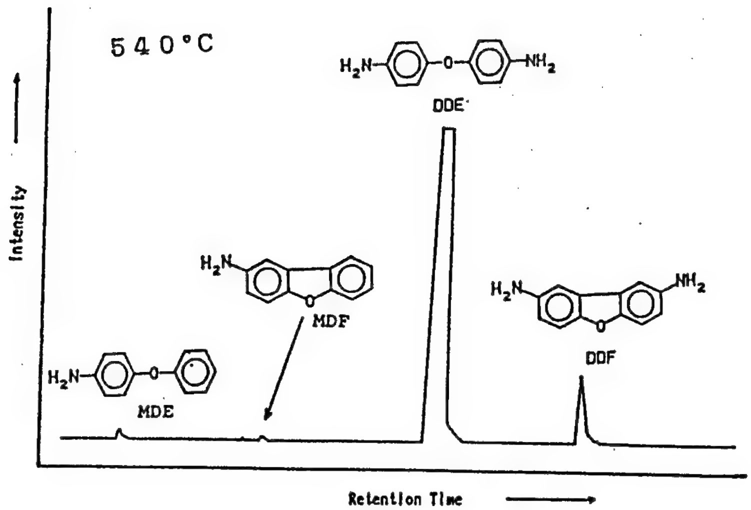

Figure 5. GC-MS Analysis of the Basic Products

Table 2 shows the yield of polymer materials after two reactions of heat treatment and hydrolysis according to their reaction mechanism. Of particular interest here is the generation of phthalic acid and its yield. In other words, it is suggested that radical-like cleavages of a carbonyl group are the main reaction of decomposition of pyromellitimide skeleton since, in their temperature area, every imide group is not necessarily decomposed and because it is considered that radicals A and B which have escaped from hydrogen trapping are polymerized to provide refractory products with high molecular weight. It is interesting that the high-order structure of polyimide has an influence on carbon structure, as stated above, through the radical reaction process of such thermal decomposition. To make the structural relationship between polyimide and postsintering carbon more clear, it seems to be necessary to make a more detailed study of the carbonization process (thermal decomposition).

Table 2

	Weight loss (%)	Overall yield (%)				
		DDE	DDF	MDE	MDF	PA
Kapton	-	93.0	-	-	-	-
450°C	0.6	93.1	-	-	-	-
500°C	1.6	83.0	0.7	-	-	1.2
520°C	3.1	76.4	2.2	0.2	-	13.4
530°C	6.2	55.9	1.4	0.2	-	5.4
540°C	10.3	38.5	2.2	0.4	0.4	5.3
550°C	17.1	12.4	1.2	0.2	-	2.6
560°C	25.2	-	-	-	-	1.2
600°C	36.0	-	-	-	-	-

4. Production of Graphite Fiber by Polyimide/CF Complication*

A carbon fiber is, in general, of refractory graphitization quality. A vapor phase grown carbon fiber (VGCF) is known to be a good graphite fiber, and is expected to be utilized as a conductive material, except for the disadvantage of not being able to obtain long fibers over 30 cm.[10] On the other hand, it has already been reported that the conductivity of a commercial kapton film treated at 3,000°C exceeds 10^4 S/cm,[11] and it is conceivable that fibers could be produced while adequately utilizing its property by controlling the high-order structure. As stated before, PI provides manifestation of in-plane orientation through a simple operation involving making PI films into imide on the substrate, and, when treated at high temperature, offers graphite with good crystal structure. Utilizing this property, the authors produced a PI layer on the surface of the base material of carbon fiber monofilament, sintered this composite fiber, and then tried to produce a fiber with a graphite layer (Figure 6).

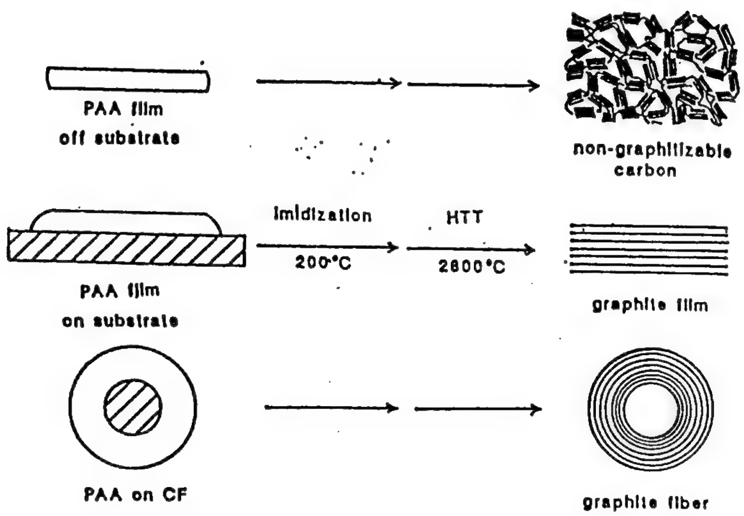

Figure 6

A commercial PAN carbon fiber (7 μm in diameter) was used as a specimen, a PAA layer of about 6 μm was deposited and polymerized on its surface and then treated for imide at 200°C, and a composite fiber could be obtained. Figure 7 presents SEM photographs of specimens obtained by treating this fiber at 800°C and 2,800°C. PI, as a film, undergoes linear contraction of about 20 percent, but in SEM observation of films treated at 800°C, no cracks resulting from this contraction could be observed. In a section of a film treated at 2,800°C, on the other hand, a layer structure showing good graphite orientation could be observed in a PI derived portion. As a result of X-ray analysis, an 004 profile showed a composite pattern comprising broad peaks on the low angle side and a sharp one on the high angle side (Figure 8). The former is derived from a carbon fiber of refractory graphitization quality,

*The present research was carried out under collaboration between Ulvac Corporation and Yoshikazu Takahashi.

and the latter from a graphite layer with a good surface. Spacing of the PI-derived graphite layer found from this pattern was 0.3362 nm, slightly low in crystal character when compared with the value of 200-on (Table 1) of the specimen heat treated under the same conditions. This is presumably because graphitization is prevented at the points where the graphite layer bends along irregularities on the carbon fiber surface. Therefore, it is expected that the crystal character of the surface layer can be improved through selecting a core fiber, etc.

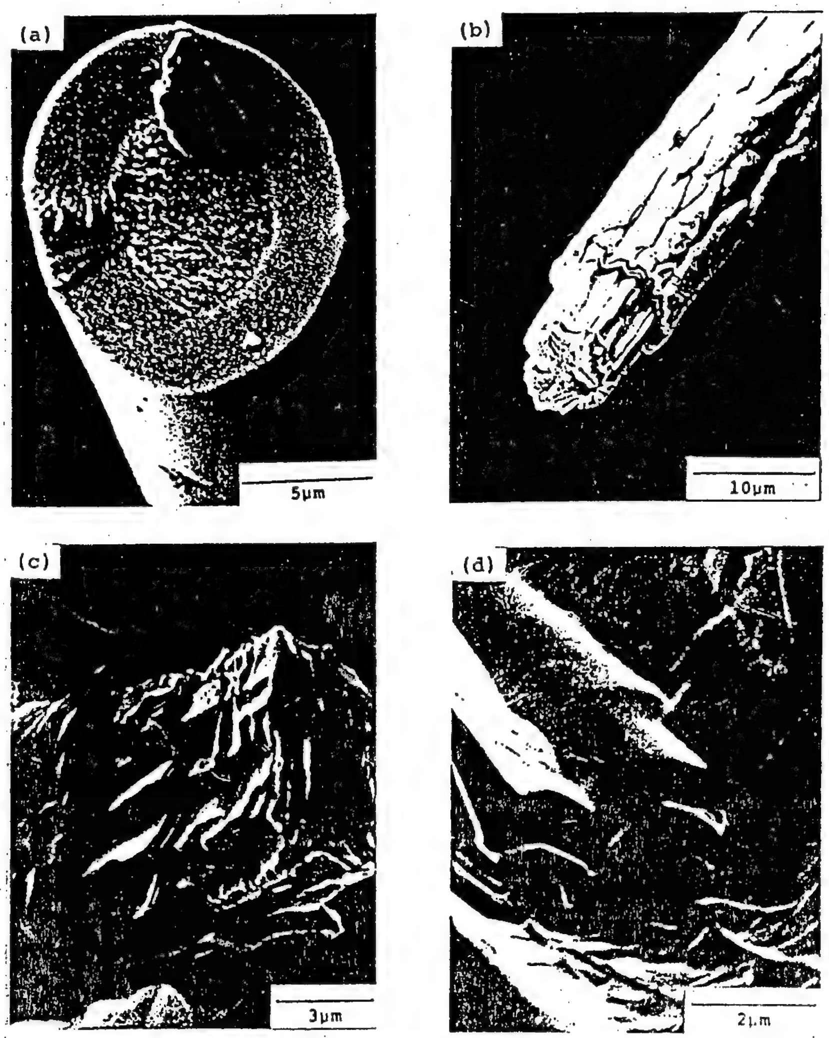

Figure 7. SEM Photographs of the Composite Fibers After Heat-Treatment: (a) 800°C; (c-d) 2,800°C

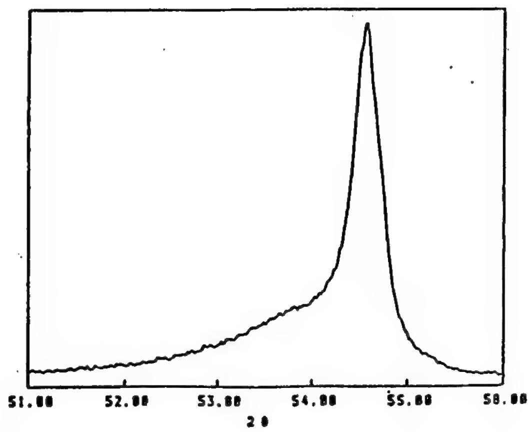

Figure 8. 004 X-Ray Diffraction Curve of the Composite Fibers Heat-Treated at 2,800°C

The authors also produced a similar composite fiber by a method for coating a PAA/dimethylacetamide, confirming that the PI layer was of free-graphitization quality.

5. Conclusion

Polymers conventionally used as materials for carbon have been limited to a few, including PAN and a PF resin. To further utilize properties of carbon in the future, it will be necessary to provide a structural design of polymer materials that considers carbon properties. To this end, it is important to clarify the difficult process of carbonization and to make clear the structural relationship between the two.

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Hi•CAST Process for Engine Components

916C1014 Tokyo NAINEN KIKAN in Japanese Dec 90 pp 63-71

[Article by Toshio Ogiwara of Izumi Industries, Ltd.]

[Text] **1. Introduction**

Among the methods for molding raw materials, the gravity diecasting method has been applied widely because of its highly flexible shape, dependable production, and lower price compared to other methods. The forging method used for molding, in turn, has been used in the manufacture of objects of complex functions because of the high strength and high quality of the products though they are limited in the freedom of their design and more costly when compared to those of the former method.

The Soviet Union researched a molding method that combines the advantages of the above two methods in the middle to late 1930s and it was reported to Japanese researchers by Yanagisawa as "melt forging." This method, however, was not practical and is now usually called squeeze casting or squeeze forming because it solidifies materials under high pressure. In Japan, it is called high-pressure solidification casting.

When this process reached practical application through Izumi Industries, Ltd., the company developed a variety of unique molding technologies and registered them under the trademark Hi•CAST, which currently is not only finding applications in the pistons of the internal combustion engine but also expanding its application to other components requiring aluminum alloys.

Many technological report publications on high-pressure solidification casting are now available that highlight the potential value of the method. Part of the developmental research conducted by Izumi Industries, Ltd., is described below.

2. Melt Forging and High-Pressure Solidification Processes

When initially introduced to industry as the melt forging method, it was comprised largely of a plunger pressure method and a direct force method. The molds used in these methods are similar to those used for forging, producing

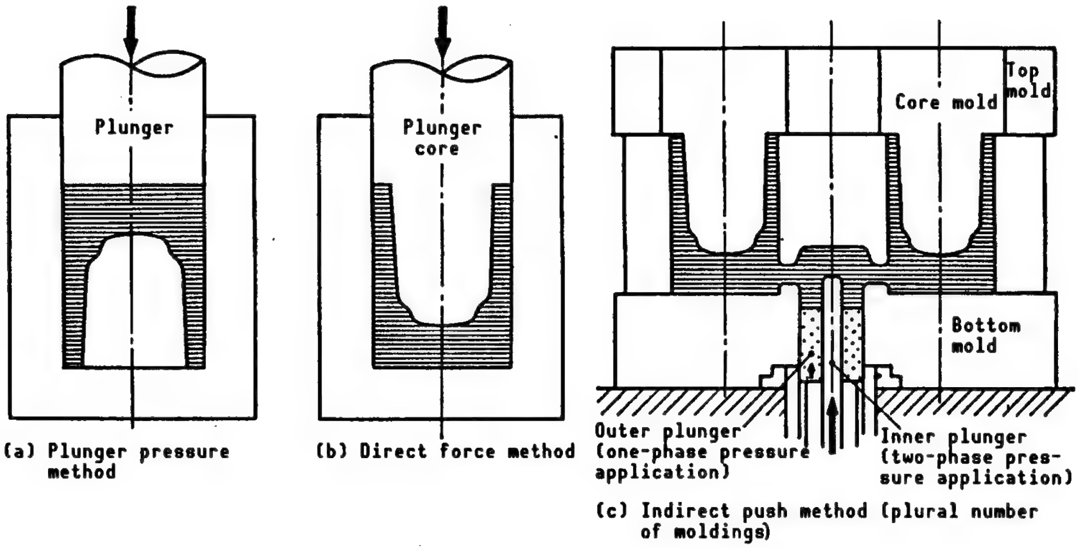


Figure 1. Classification of Hi•CAST Process

a product that appears to have been forged. In fact, it is very hard to apply pressure to an aluminum alloy melt in order to subject it to plastic deformation. In addition, the mold used in both of them affords little flexibility to change the shape of the product and allows only a limited number of products per mold, despite a simple structure, low cost, and a high weight yield; furthermore, this method involves difficulties in melt pouring such as high precision in the quantity of the melt poured and the perturbed melt flow. For these reasons, an indirect push method has recently superseded the above two methods (Figure 1).

Although the above methods use applied pressure, the principle of oriented solidification, the essential property of gravity diecasting, undeniably dictates the process; therefore, these methods only represent a high-pressure solidification casting.

2.1 Hi•CAST Process

When casting an object, thin parts generally solidify earlier, producing higher density and higher strength microstructures whereas thick parts solidify later, producing a rough and lower strength microstructure because of shrinkage. High-pressure solidification castings apply pressure to the melt in the process of molding, allowing the melt to have intimate contact with the mold, to solidify at greater rates, and to acquire microstructures more uniform and compact; the thick parts of the product, however, suffer phenomena similar to those seen in most casting methods such as those referred to above.

Izumi Industries, Ltd., therefore, has established the Hi•CAST process or a two-stage pressure application of high-pressure solidification casting processes on the assumption that the high-pressure solidification process essentially applies pressure to the melt passage part and the melt solidification part added to a molding system otherwise identical to the

Table 1. List of Different High-Pressure Casting Processes for Aluminum Alloys

Item	Melt pouring method	Melt pouring rate at melt inlet m/s	Thickness at melt inlet mm	Applied pressure (kgf/cm^2) (pressure application method)	Casting temperature °C	Feature
1. General diecasting methods	High-speed spraying	30~60	0.5~2.5	500~1,000 (plunger: 1 phase)	600~650	Yield: highest
2. GF method (gas free)	↑	↑	↑	500~700 (Depressurizing in mold)	↑	No bubble formation
3. Die-casting method/ with squeeze	↑	↑	↑	1,250· 2,500 (plunger cavity)	=660	Yield: high, casting nests scarce
4. PF method (pore free)	↑	↑	↑	↑ (Replace w/reactive gas)	600~650	No bubble formation
5. Laminar-flow die-casting	Low-speed laminar-flow filling	0.5~0.7	5~15	1,500 (plunger: 1 phase)	=700	Yield: high, casting nests scarce
6. Method (Accurad)	↑	0.3~2.5	↑	500~1,000 (plunger: 1 phase)	700~720	Casting nests almost nil
7. Hi•CAST method (Hi-pressure)	↑	0.15~0.4	Thickness greater than that in entire product	500~2,000 (plunger: 1 phase)	700~800	High quality, high thickness

[continued]

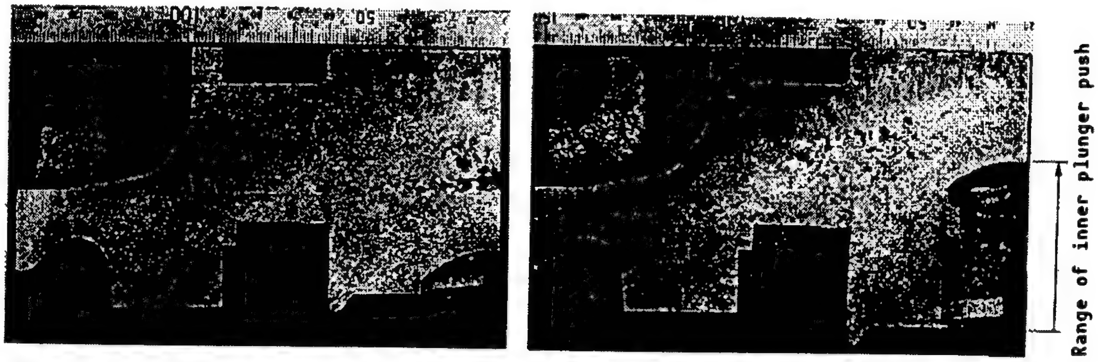
[Continuation of Table 1]

Item	Melt pouring method	Melt pouring rate at melt inlet m/s	Thickness at melt inlet mm	Applied pressure (kgf/cm^2) (pressure application method)	Casting temperature °C	Feature
8. Squeeze forming	Low-speed relative flow filling	≈0.2 (rising in the cavity)	—	1,000~2,000 (direct forcing)	700~750*	Uniform strength
9. NDC method (New Die Cast)	Low-speed laminar-flow filling	1~2	Thickness greater than that in entire product	200 (plunger)	700*	Large-size fusible core admissible
10. Gravity diecasting method (for reference)	Gravity laminar-flow filling	<2	Arbitrary	Gravity	700~800	Degree of freedom for large molding Flexible core admissible
Reference numbers	Note: References 5-9 [not reproduced] belong to the high-pressure solidification casting process.					

[* assumed]

ordinary gravity diecasting process and that the main structure of the cast is similar to that of the hard diecast. The Hi•CAST process is compared with other high-pressure casting processes in Table 1.

The Hi•CAST process has a melt flow rate at the melt inlet that is far below those for other methods; this results from conducting a slow laminar-flow rate feeding of the melt from a melt inlet of an extremely wide cross sectional area in order to prevent unfilled portions in the mold because of the back pressure arising from the gas (air) remaining in the mold cavity. The temperature of the melt during feeding, therefore, is kept at a higher level than for the other methods. This leads to a higher heat impact on the diecast making it important to properly select the die material and to apply a proper cooling method to the mold.



Outer plunger single-phase pressure application

Outer plunger-inner plunger two-phase pressure application

Figure 2. Effect of the Two-Phase Pressure Application

This two-stage pressure is effectively applied to the casting of thick aluminum alloy moldings and aluminum alloy moldings of wide solidification ranges such as AC4C and affords moldings for components needing high quality and high function (Figure 2).

2.2 Mechanical Properties of Aluminum Alloy Made by Hi•CAST Process

The Hi•CAST process, which allows filling and solidification of melts under high pressure, is available not just for casting but also for the manufacture of malleable alloys whose melt flow is poor and many other kinds of aluminum alloys.

Many Hi•CAST moldings have greater tensile strength and elongation than those of gravity diecasting (Figure 3).

A greater elongation is particularly notable in the alloys AC4A, AC4C, A354, and 7475, which have wide solidification ranges, and a high strength in the alloys' moldings are free of shrinkages and gas-porosity and their micro-structures are finer (Figure 4).

Figure 5 presents fatigue limits of the alloys as determined by a rotary-bending test. Hi•CAST moldings improved their fatigue limits compared with the gravity diecasting ones, ranging from room temperature to high ones and hence give superior mechanical properties.

2.3 Examples of Application

(1) Scroll for Car Air-Compressors

Scrolls have laps in the form of an involute: the fixed part and the movable part mesh and rotate together. The lap is subjected to a high side pressure and hence needs to have high rigidity, high strength, and high resistance against fatigue (Figure 6). Scrolls made by Hi•CAST have improved and satisfactory properties in this connection and, in addition, by raising the height of the lap, produced light weight and compact products while maintaining equivalent volume for the discharge.

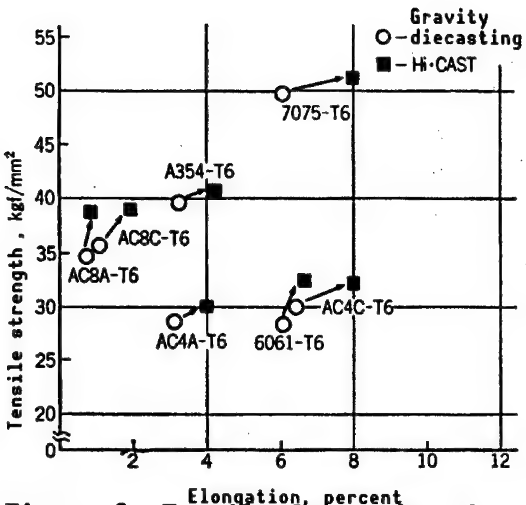


Figure 3. Tensile Strength and Elongation in Materials Made by Hi•CAST Method

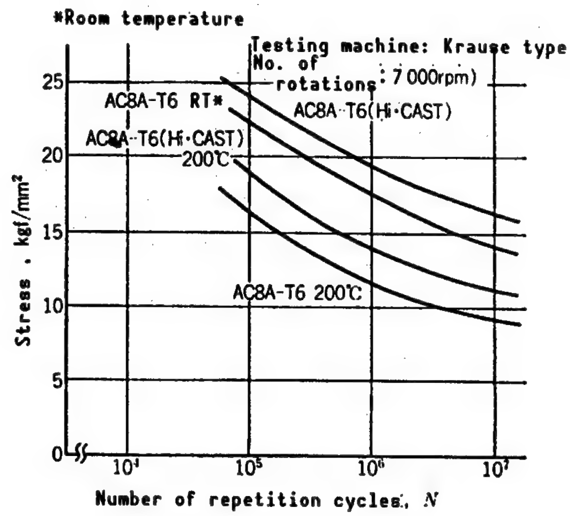
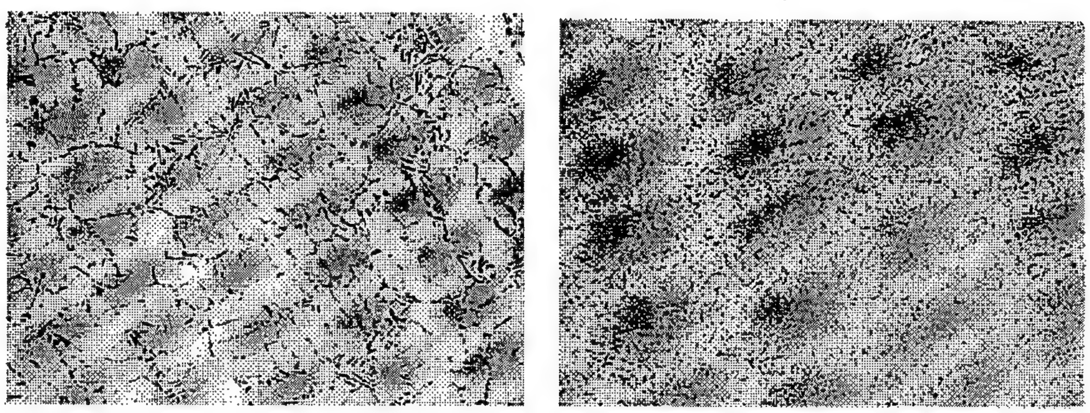


Figure 5. Fatigue Limit of Materials Cast by Hi•CAST Method



(a) Gravity diecasting

(b) HI-CAST

Figure 4. Microscopic Structure of AC4A (x100)

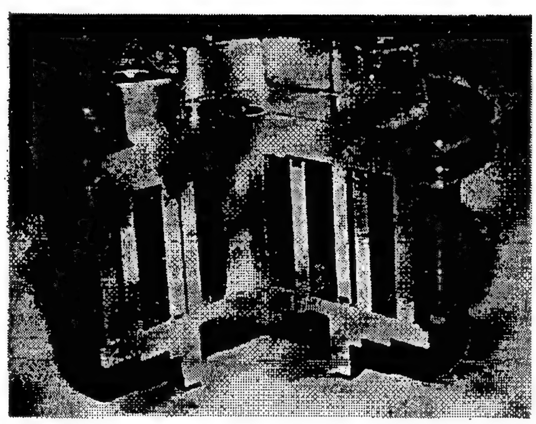
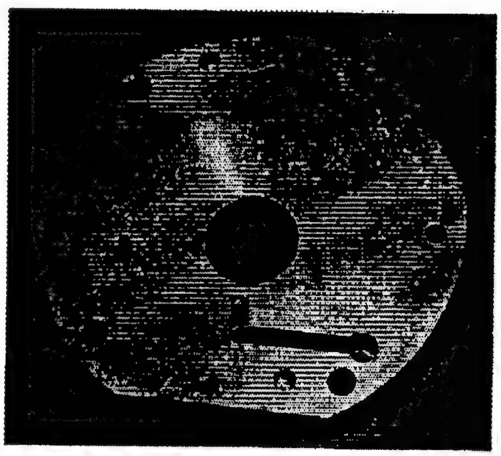


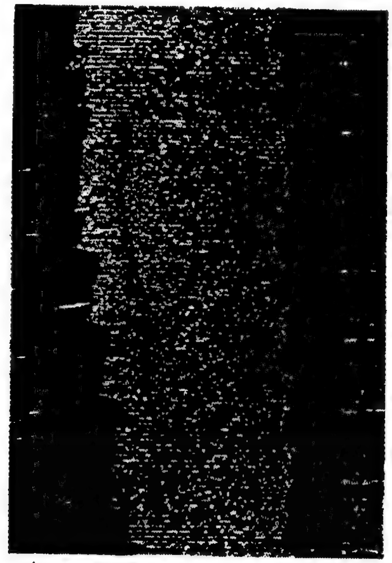
Figure 6. Scroll in One Set

(a) Cylinder part

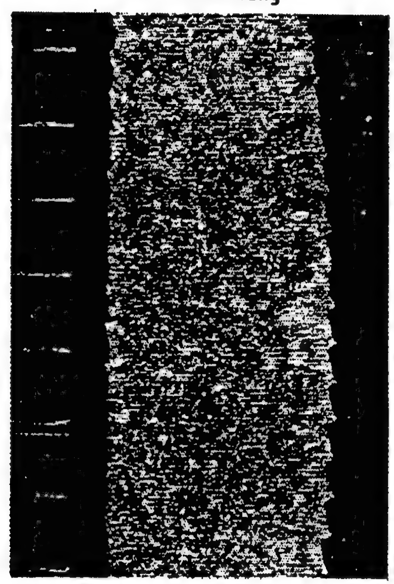


(b) Intermediate cover

Figure 7. Components for Vacuum Pumps



(a) Diecasting



(b) HI-CAST

Figure 8. Microstructure of Cast Rotors

(2) Components of the Vacuum Pump

Since components of vacuum pumps need air-tightness to maintain the vacuum condition, gravity diecasting products generally have failed in this consistently because of the presence of diecasting defects such as pinholes and shrinkage resulting largely from heavy thickness of 28 mm. The users have had to depend on extruded materials that have been subjected to mechanical processing for a finish. The Hi•CAST method, in this connection, curtailed the amount of mass removed mechanically in the finishing process and simplified the process.

Fusible cores are used to provide holes for the passage of lubrication oils to the intermediate cover (Figure 7) in order to dispense with such processing steps as drilling and subsequent plugging, thus reducing the total number of mechanical working steps.

(3) Cast Rotor

Diecasting methods have so far been applied to cast rotor filling some of the very narrow grooves of their steel cores with pure aluminum. These methods still allow development of diecasting defects and subsequently reduce the motor efficiency remarkably. The Hi•CAST method has eliminated the diecasting defects, leading to a 15-percent improvement in motor efficiency and a successful improvement in the yield of the product (Figure 8).

3. Hi•CAST Development of Composite Materials

The Hi•CAST method is capable of providing high-quality, high-function products as seen above, but its greatest feature is its pressure capacity for manufacturing a composite material, which has been reported in many technological articles and other publications as metal matrix composites (MMC).

MMCs have metals coupled with other materials to give them superior strength resistance against heat and wear, etc., and are classified largely into two types: one using fibers for reinforcement and called fiber-reinforced metal (FRM), and one coupled with a material other than fiber. Figure 9 presents a list of MMC types.

- MMC
  - CFRM (Carbon fiber-reinforced metal)
  - ALFRM (Alumina fiber-reinforced metal)
  - WRM (Whisker-reinforced metal)
  - In addition, fibers made from boron, silicon carbide, etc., are also used for reinforcement
  - Porous metals (sintered stainless steel, Ni-foam, etc.)
  - Ceramic particles (SiC, Si_3N_4, and Al_2O_3 are frequently used)
  - Intermetallic compounds ($NiAl_3$, etc.)

Figure 9. Classification of MMCs

3.1 Features of MMCs

Features described below are those for pistons made from FRM by Hi•CAST using an aluminum alloy for the pistons, AC8A, as the matrix.

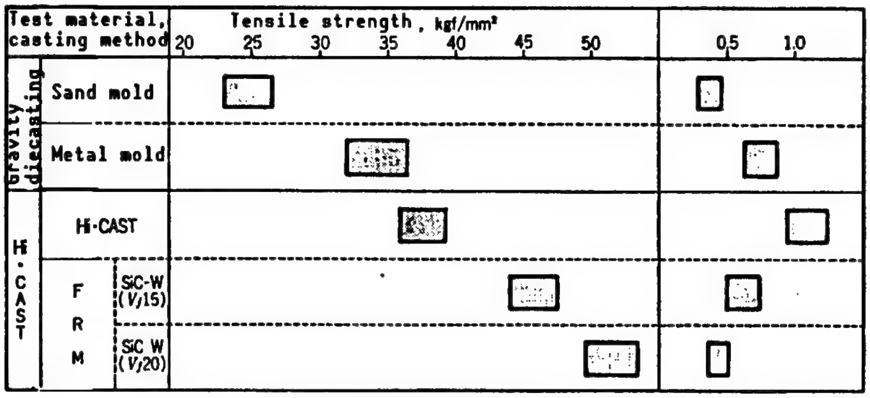


Figure 10. Mechanical Properties of AC8A(T6) Alloy

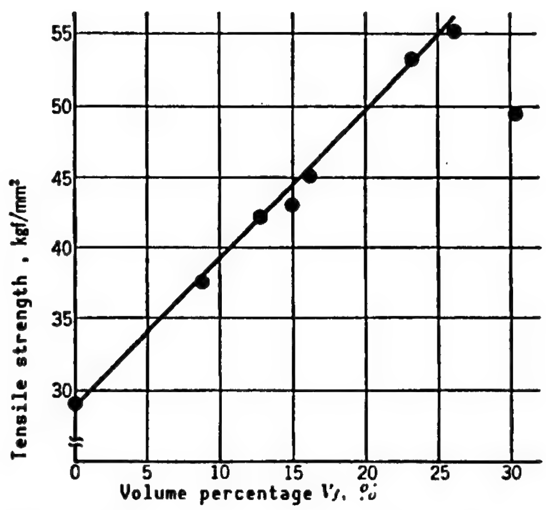


Figure 11. Volume Percentage Vs. Strength for FRM Reinforced With SiC Whiskers

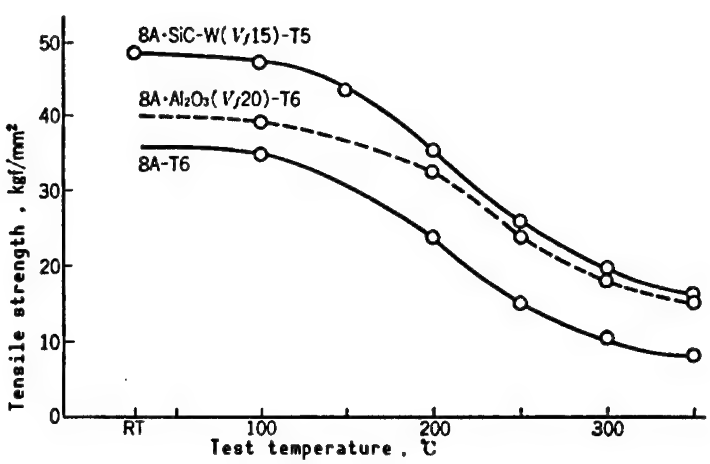


Figure 12. Tensile Strength of AC8A Composite Material

(1) Mechanical Properties of AC8A

Figure 10 lists the tensile strength and elongation of moldings for different molding methods and for FRMs using SiC whiskers. The figure indicates that Hi•CAST moldings are superior to gravity diecasting ones in both properties and that FRMs using SiC whiskers have further enhanced tensile strength. Figure 11, in turn, presents changes in the mechanical property of FRMs with increasing SiC content. FRMs made from AC8A and SiC whiskers have their strength raised with increasing whisker volume until whisker volume reaches percentage V_f of 25 but is maximum strength at about 30 percent V_f, because the metal melt fails to fill the preform of fiber moldings completely at that volume percentage and above. It seems reasonable to use V_f at about 13~18 percent in selecting FRMs involving SiC whiskers, allowing for economy, consistent quality, machining ease, etc.

Figure 12 shows the relationship between tensile strength and temperature. AC8A FRMs using SiC whiskers remain stronger than the matrix metal even at high temperatures, indicating that the rate of improvement in strength is greater in the high-temperature range.

(2) Strength of the Interface Between Composite Part and Pure Alloy Part

Strengthening of a composite material may be accomplished by composite formation for an entire object or its parts, and, because of the costs, the latter design is chosen predominantly for the manufacturing of pistons. Thus, the bonding reliability between the composite part and the pure alloy part is important. Figure 13 presents the interface strength, and Figure 14 shows the interface for Ni-foam MMC and Ni-Cr-foam MMC.

The bonding strength for the MMC of Ni foam is only comparable to and not greater than that for Al·FiN because of intermetallic compounds produced by the heat treatment applied to raise the resistance against wear of the former material. The MMC of Ni-Cr foam, in contrast, has its interface-bonding strength raised notably since this MMC scarcely allows development of intermetallic compounds. FRM exhibits no lowering of bonding strength at the interface since its matrix is essentially identical with its parent material of pure alloy.

(3) Resistance Against Thermogenic Crack

Figure 15 shows the method for thermal shock tests and Figure 16 relevant test results.

SiC-whisker FRMs are superior to their parent material of pure alloy, AC8A, in terms of the number of test cycles and the length of cracks, which indicates that the former has higher resistance against thermogenic crack. It is important to watch changes in temperature gradient resulting from the addition of reinforcement fiber occurring at such a site as the combustion chamber above the piston head, where thermal stresses are imposed by a high-temperature gradient; as seen in Figure 17, materials like SiC whiskers that are of high thermal conductivity are favored for this use.

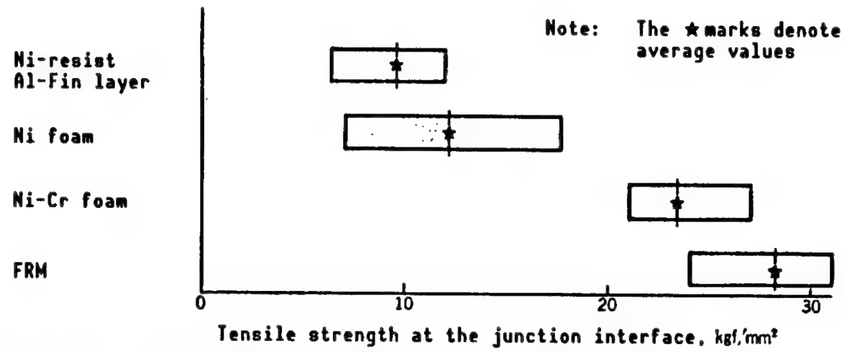


Figure 13. Strength at Junction Interface Between Composite-Material Part and Parent-Material Part of Al Alloys

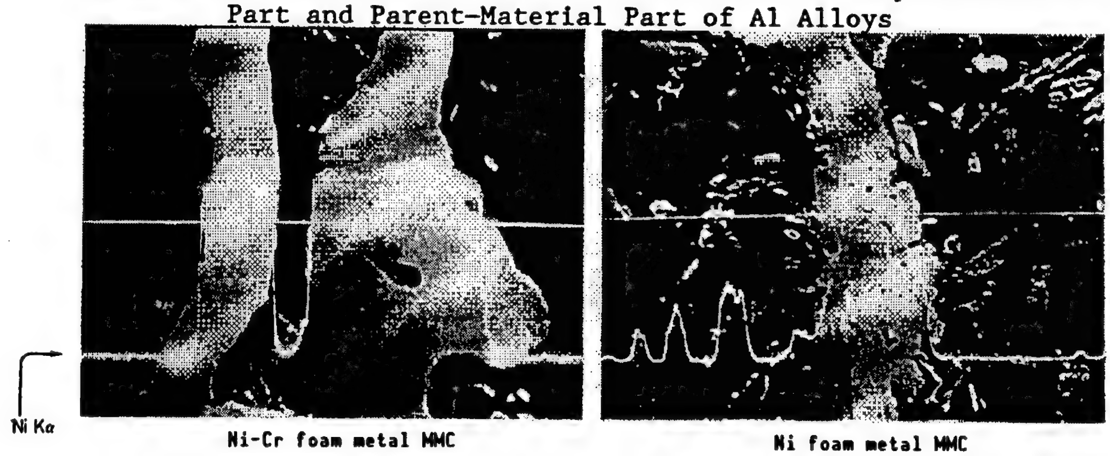


Figure 14. SEM of Foam Metals

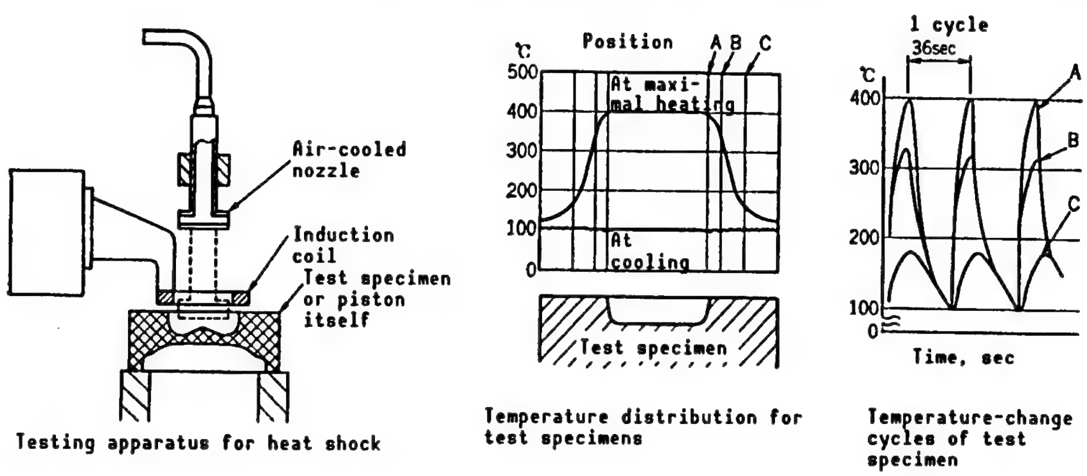


Figure 15. Testing Method for Heat Shock

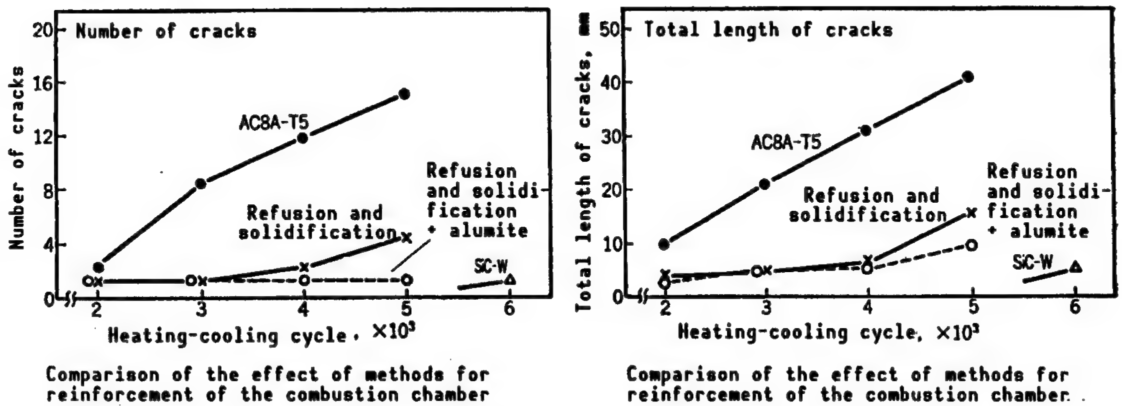


Figure 16. Results of Heat Shock Tests

(4) Resistance Against Wear

MMC not only has its mechanical strength improved as seen above but also has its resistance against wear enhanced effectively. Figure 18 compares the wear resistance values of MMCs with different reinforcement materials against AC8A as a standard value of unity. The foam metal in the figure implies Ni foam, which, after having been turned into a composite, is subjected to heat treatment leading to the formation of the intermetallic compound AlNi at the junction interface between the Ni foam and the matrix improving its wear resistance (Figure 14).

It is important to note in conducting a wear test for MMCs that, though they may have an improved wear resistance, they sometimes also produce lower resistance in the coupled material during friction.

Figure 19 presents the results of an engine test for investigation side-surface wear produced in the friction between a piston-ring groove reinforced with SiC whiskers and a piston ring made of different materials.

FRMs involving ceramic fibers, etc., when coupled with piston rings that are subjected to chromium plating and that have been used intensively produce extensive wear on both the ring and the groove. When the ring is replaced with the one made from SUS to counter this friction wear, the amount of wear falls notably.

Nevertheless, a piston-ring groove made from Ni resistant cast iron and coupled with a general ductile cast iron ring produces far less wear than the above ones.

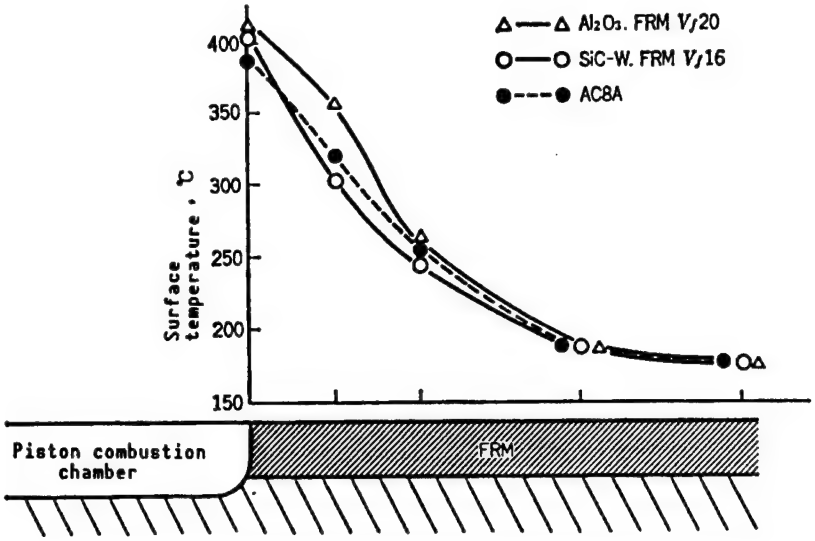


Figure 17. Temperature Distribution for Different FRM-Test Specimens

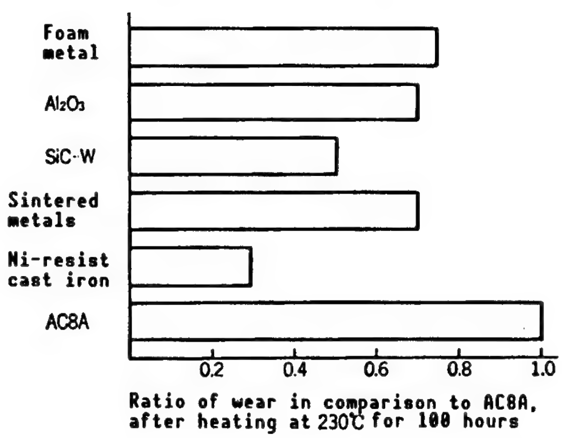


Figure 18. Wear Resistance for Different MMCs

4. Practical Application Examples of the Piston for Diesel Engines Subjected to High Loads

Pistons for diesel engines, the major product of Izumi Industries, Ltd., have been in need of new technological development because of growing legal regulations on engines becoming widespread. Past technologies are no longer capable of coping with them, that is, the corporation has been trying to improve the function of pistons because of requirements for fewer public nuisances produced by engines, for low fuel costs, for lightweight cars, for application of high loads on engines, etc. The corporation, at this juncture, has been able to elicit various superior properties from the aluminum alloy AC8A by means of the Hi•CAST method and MMC application. In these technological developments, the corporation has made notable advances in the technology for fusible cores that withstand high pressure and in the iron inserted casting technology. Combining these technologies has produced a diesel engine capable of working under high loads.

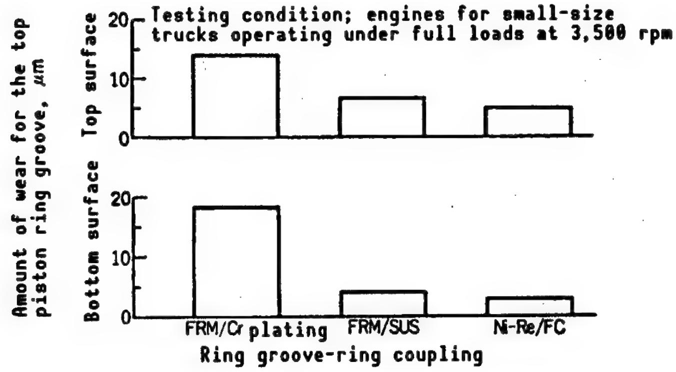


Figure 19. Amount of Wear for Different FRM Piston-Ring Grooves

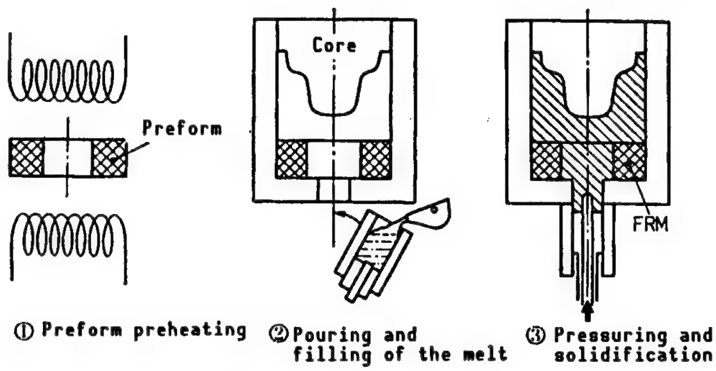


Figure 20. Example for Manufacture of FRM Pistons

4.1 Example for Manufacture of FRM Pistons

An example for the manufacture of FRM pistons is shown in Figure 20.

(1) A premolded preform (fiber molding) is subjected to preheating to facilitate the impregnation of melts into the fiber.

(2) After having set the preheated preform in the cavity of a mold, the melt is poured to fill the cavity.

(3) The metal melt is allowed to impregnate the preform as completely as possible by pressure application and then to solidify.

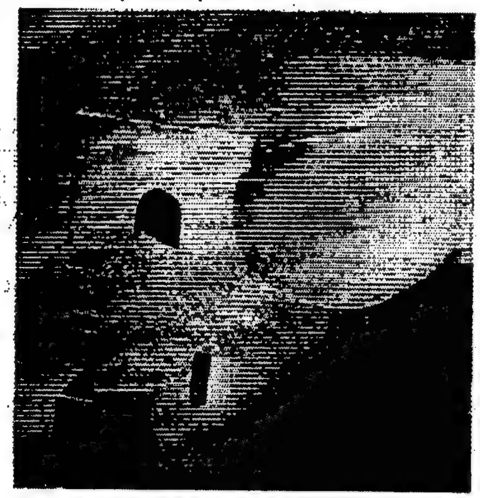
4.2 Example of Practical Application

Examples for practical applications of diesel engine pistons are presented in Figure 21. Relevant technologies are shown in parentheses.

(1) Improvement of resistance against thermogenic cracks at the head of the pistons and at the inlet of the combustion chamber (FRM) (Figure 21(a).

(2) Lowering the temperature at the head and in the vicinity of the piston-ring grooves (FRM, involving a cooling cavity) (Figure 21(a)(b).

(a) FRM Al-FiN piston with 133ϕ cooling cavity incorporated



(b) Ni-foam MMC piston with a 100ϕ cooling cavity incorporated

Figure 21. Pistons for High-Load Diesel Engines

(3) Improvement against wear of the piston-ring grooves (MMC; Ni-resistant cast iron ring groove Al-FiN coupling) (Figure 21(a)(b)).

5. Pistons for Gasoline Engines

Lightweight cars and high loads on engines have been the general tendency for gasoline engine pistons as well as for diesel engines. The thin structure of the piston following this line still involves a lowering of rigidity for the entire engine, and one relevant indispensable way to counter this disadvantage is by applying ribs to the inside of the piston skirt, for which the casting has to be undercut with respect to the drawing or withdrawing. These requirements are being handled by Izumi Industries, Ltd., with Hi•CAST (Figure 22).

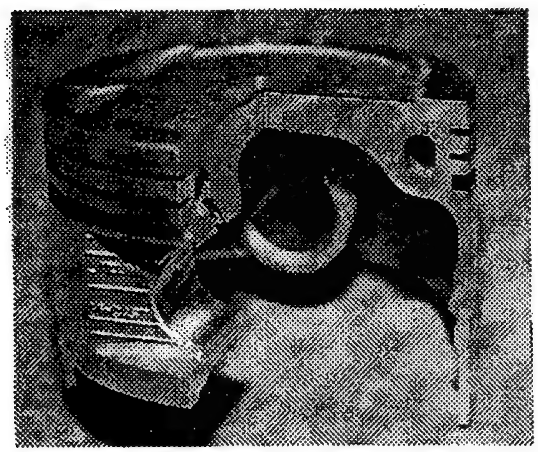


Figure 22. Piston for Gasoline Engines Made by Hi•CAST

6. Conclusion

The Hi•CAST method, compared with diecasting and other casting methods, allows a wide range of choice for aluminum alloys and affords products of better quality as described above.

No more than 10 years has passed since the high-pressure solidification casting found its practical applications with the method being interpreted in a wider sense as representing merely an application of pressure during casting by some circles of researchers. Nevertheless, in recent years, it has become better understood that differences in the quality and property of the products arise from the application of different amounts of pressure, and thus the methods have been classified into high-pressure and intermediate-pressure. This indicates that the potential for the Hi•CAST method is understood.

It is conceivable that the future needs for lighter cars probably will become greater and that the material for car components must shift from iron to aluminum. Izumi Industries, Ltd., plans to adapt itself to new areas of applications as it expands the applications of the Hi•CAST method to more products.

ISDN, Its Impact on Visual Communication

916C1008A Tokyo OPTRONICS in Japanese Oct 90 pp 47-51

[Article by Shirakawa Hidetoshi, Transmission System Project Group, NTT Network Development Center]

[Text] **1. Introduction**

It is generally predicted that video, together with the currently prevalent audio, will play a leading role in communication networks in the 21st century. This article will first outline the course our country took in video communication, which is the main subject of this special edition; it will then mention the significance of introducing the integrated services digital network (ISDN), which started service year before last as the infrastructure of future communication networks, its serviceability, and the present status of its use. In addition, the article will look far into the future of B-ISDN, supporting high-speed broadband networks centered on video systems.

2. Course of Video Communication

Figure 1 shows the course of our country's video transmission technology. The commencement of TV program relay transmission by the Public Telephone and Telegraph Public Corporation (now Nippon Telegraph and Telephone (NTT)) in 1954 between Tokyo and Osaka, aimed at future nationwide TV broadcasting, was the first instance of video communications. Then, baseband transmission using coaxial cables was applied between broadcasting stations and NTT stations. for the long distance section between NTT stations, FM transmission using microwaves in the 4 GHz band was adopted. This is still in use and supports the present nationwide TV broadcasting. Following TV broadcasting, various industrial TV video transmission systems for remote monitoring were introduced in 1976 as the so-called general communication service. At that time they were limited to local transmission, including traffic control, and adopted baseband transmission using metallic cables.

Video communication was limited to the above two kinds until the middle of the 1970s. However, as the demand increased, video service made great strides, backed up by progress in some technical aspects.

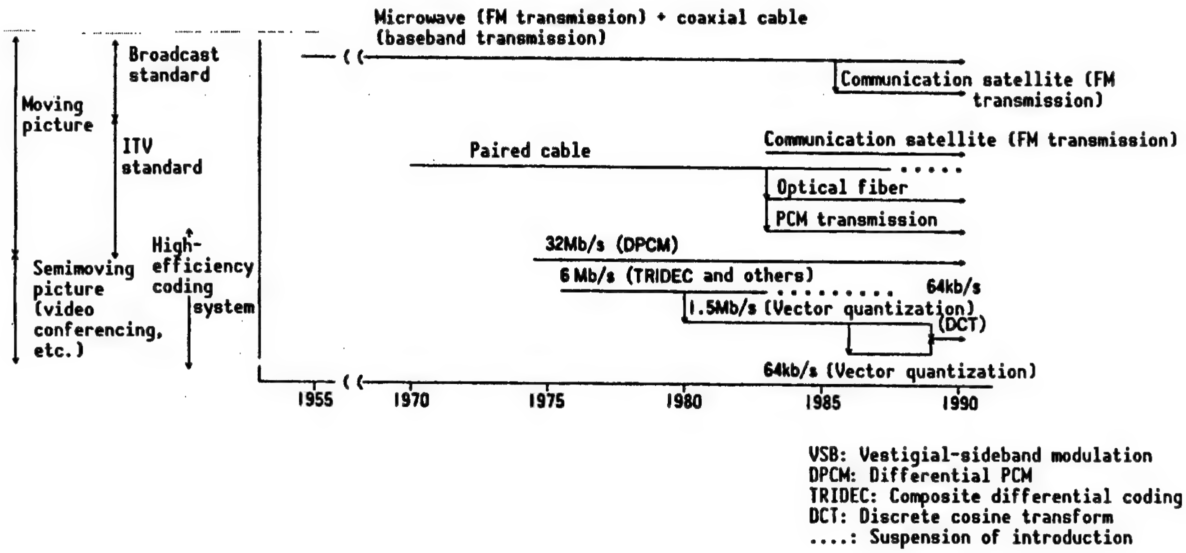


Figure 1. Course of Domestic Video Transmission Technology

First to be cited are digitizing communication networks, made possible by progress in integrated circuit (IC) technology, and the advance in video coding technology. Also, video transmission changed from analog to digital transmission, and the latter still remains in use. What deserves special mention in video coding is the progress of high-efficiency coding (band compression) technology. Although band compression is not suitable for rapidly moving pictures (called a moving picture) on air, it provides a large compression rate (which reduces the transmission speed) for slowly moving pictures (called a semimoving picture), for example, a conference in particular. While linear coding requires about 100 Mb/s, various coding technologies that compress to 6 Mb/s to 64 kb/s were developed as high-efficiency coding. This allows the holding down of cost increases due to extending transmission distance, and it is not too much to say that it made the long distance transmission of general video service possible for the first time, which bore fruit in video conferencing service.

Second is the progress in optical fiber transmission technology. Optical fiber, with transmission characteristics such as a low loss and broadband width, is a transmission medium best suited for video transmission. Optical fiber and optical elements are rapidly becoming economical, and optical fiber transmission systems are being used for all users' homes within newly established sections, so that providing high-quality service is being realized.

Third is the start of video transmission service using communication satellites. Our country's domestic communication satellite CS-1 was launched in 1983, and five satellites including private ones are currently operated. Video transmission using satellites also became active. The band of a satellite's transponder is about 30 MHz, and analog transmission by FM modulation is popular at present, but studies on digital transmission are also being made.

- Private service
  - Relay of TV broadcasting (transmission of TV broadcast programs)
  - Video transmission (General video transmission: Not for broadcasting)
  - Satellite video communication (General video transmission: Not for broadcasting)
- TV conference service

Figure 2. NTT's Video Communication Service

The future growth of video transmission making use of satellite-communication characteristics, including simultaneous transmission efficiency and nonreliance on distance, is predicted.

While video communication was outlined above from a technical viewpoint, Figure 2 shows its aspects of service. The NTT video communication service, which is roughly divided into various private television services that transmit moving pictures and to video conferencing service as a public communication service, now provides video services using 1,900 circuits.

On the other hand, with the digitization of communication networks, the high-speed digital private-circuit service (superdigital) started in 1984 added a new aspect to development of video communication. The superdigital service is a digital private-circuit service of between 64 kb/s and 6.3 Mb/s, and with it a user can form any network according to its utilization purpose, through which freely combined pictures can be transmitted in addition to telephone and data transmission service by using the above-mentioned high-efficiency coding equipment.

Mention was made only of video communication so far. Although it has well-developed technologies, it still stands at the dawn in terms of service, to our regret, and it is desired that further advances be made in the future in aspects of both needs and technological innovation. What is expected to make great contribution to the growth of video communication just as with the superdigital service is ISDN, a future communication network infrastructure, and mention will be made of its significance and prospects in the next section.

3. Present Status of ISDN

3.1 Introduction of ISDN

Until now, basic services, including data and facsimile communication, were offered mainly through telephone, but in terms of a network, they were separately provided as a telephone network and a data network. However, with the evolution of the information-oriented society, diverse service menus and the realization of various multimedia services, including the media conversion communication of data and facsimile, for instance, came to be demanded, so that development of new networks became necessary. What was created under these circumstances is the Integrated Services Digital Network (ISDN), which is a public communication network providing various services uniformly, flexibly, and efficiently.

Similar to the superdigital service, the ISDN digitizes all signals from terminals, so they can be handled uniformly within the network, disregarding their former attributes. As shown in Figure 3, the ISDN implements transmission between users' networks through metallic cables or optical fiber; it consists, within the network, of a digital switching system connecting various communication, an intelligent processing device performing media conversion and storage, and various digital transmitting channels for long-distance communication. It not only allows the providing of a variety of services, such as facsimile communication, video conferencing and telephone message communication, intercomputer communication, and audio program broadcasting in addition to the telephone, but it also creates a number of additional services including a charge advising service.

3.2 ISDN Service

Structuring ISDN is a worldwide trend, and its service is provided to users through digital interfaces unified worldwide. In our country, ISDN service began INS net 64 in April 1988 and the circuit switching service of INS net 1500 in June 1989. ISN net 64 provides two information circuits (B channel) of 64 kb/s and one signal circuit for control (D channel), that is, 2 B + D circuits. On the other hand, INS net 1500 has a maximum capacity of 24 B channels as an information channel, within which any combined circuit of B channel, H_0 channel (384 kb/s) and H_1 channel (1.5 Mb/s) can be provided if necessary. Furthermore, packet switching service using either B channel or D channel was added in June 1990 to improve the service. In any case, a user can communicate freely with any desired counterparts (in any number) through any desired channels (in any number) whenever necessary. Thus, initial steps have been taken toward the ISDN age.

With more than 10,000 subscribers at present, the number of ISDN users are steadily increasing. The growth of demand for ISDN service is particularly great this year, and the major part of the demand is for commercial use. However, the ISDN service is expected to rapidly spread into general households to replace conventional telephones as cost reductions for various terminals and diversification of forms of communication advance. For video service under these circumstances, visual telephone and video conferencing using still

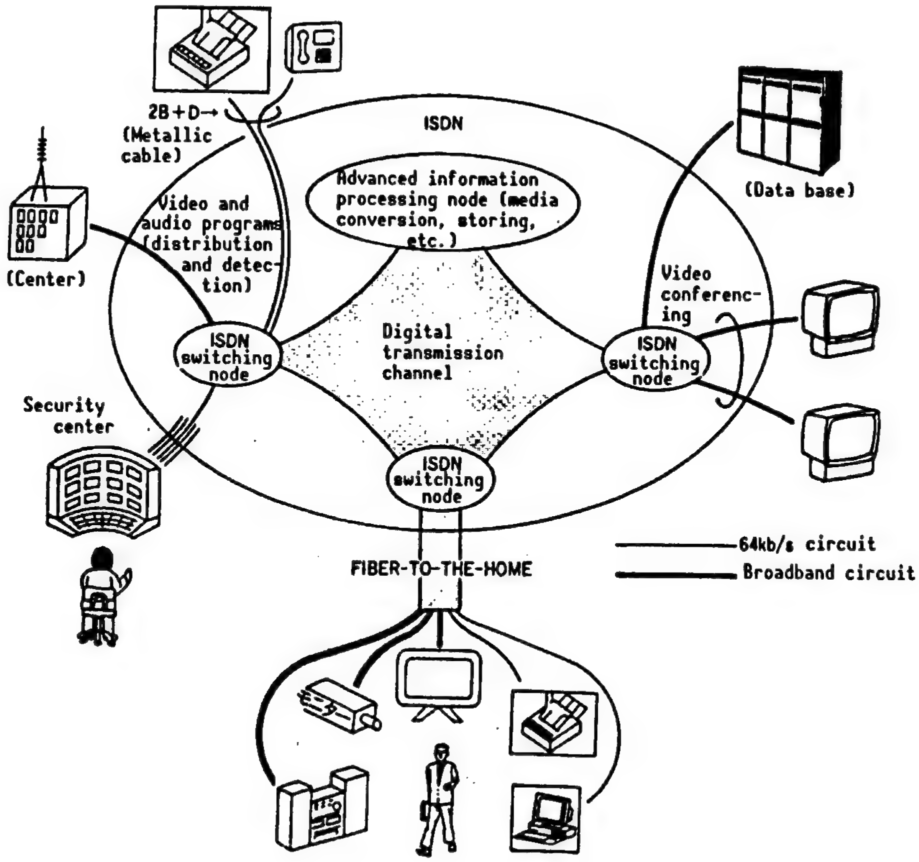


Figure 3. ISDN and Service Application

pictures and high-efficiency coding technology will grow as the main form of its utilization.

4. Future Prospects for ISDN

4.1 Expansion of High-Speed Broadband Service

Amid the changing social trend toward the 21st century, involving the advance in individualization as well as aging, the industry's software orientation, the globalization of economy, and the aggravation of environmental and urban problems, the demand for information communication service is expected to be diversified. Characteristic among other things is the demand for high-speed broadband communication service centered on pictures, aimed at transition from the current "aural" communication to "visual" communication and "more convenient and more comfortable" communication, which are symbolized by a satellite office, work at home being popularized, shopping by pictures, and linkage of pictures and data by computer graphics. To meet this demand, B (broadband)-ISDN, a high-speed broadband network, expediting the arrival of the true multimedia age, becomes necessary in addition to the present communication service of a maximum of 1.5 Mb/s.

4.2 Outline of B-ISDN

Although the communication service by the present ISDN is limited to speeds below that of the primary digital stage interface (1.5 Mb/s), B-ISDN can provide service with a speed of 150 Mb/s, 100 times the current rate, or faster. Needless to say, information at various speeds below this level can be communicated simultaneously. To realize such communication service, development of some key technologies concerning the ISDN structural technology, shown in Figure 3, is under way as follows. One is optical transmission technology capable of economically providing users with high-speed signals exceeding 150 Mb/s. In the future, optical fiber will be introduced to subscribers, and the age of FIBER-TO-THE-HOME (FTTH) will eventually come when optical fiber is installed around houses.

Next is a new means of digital signal transmission called the asynchronous transfer mode (ATM). In a way, ATM is superhigh-speed packet communication that transmits various signals after dividing them all into the unit of cell. This will make it possible to handle them within a network, disregarding the information rate of the original signals. Accordingly, it will become possible to efficiently transmit various signals of very different speeds, ranging from sound (64 kb/s) to a picture (more than 150 Mb/s).

Moreover, as a long distance digital transmission method, optical transmission capable of transmitting at 100~1,000 Gb/s, increases of 10~100 times the present speed will be realized, resulting in the economical supply of high-speed broadband service.

Furthermore, since various network operating functions will be added in the future, thanks to advances in artificial intelligence (AI) technology and fuzzy computers, a network easy to operate will be realized.

Research on these technologies is being energetically conducted in various quarters and, consequently, the age of B-ISDN will come in several years, as shown in Figure 4, and will flourish in the 21st century.

4.3 B-ISDN and Video Communication

In regard to expansion of video service employing B-ISDN, high-definition large-screen video communication represented by high-definition television (HDTV)— multiscreen video communication that transmits a large number of pictures simultaneously—and stereoscopic video communication will be realized, although all these forms of communication will be made by moving pictures rather than the semimoving pictures mainly used in current service. Additionally, in regard to video coding, the currently prevalent fixed-speed coding will be replaced by variable speed coding which has the characteristic that it is suitable for ATM's cell multiplex and makes it possible to improve quality and to communicate between terminals having different definitions from each other. Furthermore, combined with the above mentioned superhigh-speed optical transmission technology, economical and high-quality video communication service will be realized.

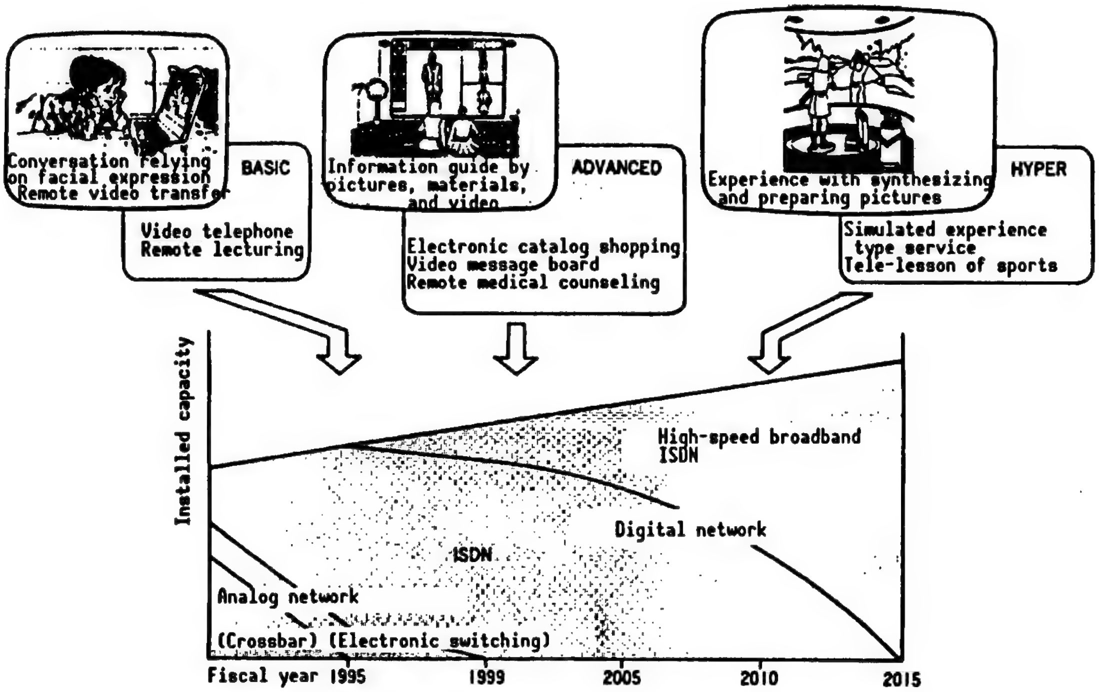


Figure 4. Expansion of Broadband ISDN Service

With the advent of the full-scale B-ISDN age, pictures will be routinized and speeded up, giving rise to various video communication services. For instance, participation-type video communication service such as simulation service in real-time and three-dimensional stereoscopic video communication service, will become popular. As a result, new services—including remote teleshopping and tele-lesson at home, video walls at underground space, interactive video simulation such as sports, games, and education, stereoscopic conferences, and stereoscopic event relay—will be created, in which ambience will be easily produced. Figure 4 shows the future prospects for evolution of ISDN as well as video communication services.

5. Closing Remarks

It is thought that communication technology will advance in response to social movements and will have a great impact on the formation of the future video culture.

HDTV, Its Image Transmission Technology

916C1008B Tokyo OPTRONICS in Japanese Oct 90 pp 57-62

[Article by Yoshimichi Otsuka, NHK Science and Technical Research Laboratories]

[Text] **1. Introduction**

Regular experimental high-definition television (HDTV) broadcasting by the MUSE system for one hour daily began in June 1989 using the No. 2 broadcasting satellite (BS-2), which transmits radio waves to homes from an altitude of 36,000 km above the equator. Following this, commercial broadcasting is planned to begin in autumn of 1990 using the No.3 broadcasting satellite (BS-3) launched in August the same year.

With HDTV broadcasting expected to be put into service, the opportunities for interstation and international program transmission and the relay of live broadcasting will increase. For these purposes, transmitters employing analog as well as digital technologies have been developed. this article will touch first on the HDTV studio standards and will then introduce the band compression and modulation systems of some transmitting systems developed so far.

2. Trends of HDTV Studio Standards

The HDTV studio standards are being discussed by CCIR. Against the 1125/60 system proposed in Japan, European countries proposed the 1250/50 system at CCIR's interim meeting in 1987. Since a recommendation cannot be finalized if the confrontation between the 1125 and 1250 systems continues, the IWP11/6 conference held in January 1989 tried to expedite the deliberation by preparing a table of standard parameters and adopting the parameters agreeing to this table. Agreement was reached on some parameters before the IWP11/6 conference held in March 1990, and a final recommendation draft to be submitted to a general meeting in May was finalized.

The agreed parameters represent photoelectric conversion characteristics (gamma characteristics), aspect ratios, synchronizing signals, chromaticity of the three primary colors, and equations of luminance and color signals (matrix). However, no agreement was reached on important scanning parameters,

such as the number of effective scanning lines and field frequency, holding the deliberation over until the next meeting.

While BTA laid down BTA S-001 in August 1987 as HDTV studio standards in Japan, SMPTE established the same standards as 240M in the United States. BTA and SMPTE are now discussing in close cooperation the digital standards to complete these standards.

Table 1 shows the HDTV studio standards stipulated in BTA S-001, but the matrix there is quoted from CCIR's recommendation draft XA/11.

Table 1. Standards of HDTV Studio

Item	Standard
Number of scanning lines	1,125 lines
Interlacing ratio	2:1
Aspect ratio	16:9
Field frequency	60.00 Hz
Line frequency	33.75 kHz
Image band	30 MHz
Sampling frequency	Y: 74.25 MHz C: 37.125 MHz
Number of horizontal picture elements (including blanking)	Y: 2200 C: 1100
Number of effective picture elements	Y: 1920 picture elements x 1035 lines C: 960 picture elements x 1035 lines
Matrix	Y = 0.2125 R + 0.7154 G + 0.0721 B Pr = 0.6349 (R-Y) Pb = 0.5389 (B-Y)

3. HDTV and Its Transmission System

HDTV transmission systems can be classified by transmission channel into wireless and optical fiber, as shown in Figure 1, and they are further classified into analog and digital transmission, respectively. Furthermore, digital transmission is classified into straight PCM and high-efficiency coding. This chapter will introduce some of these transmission systems.

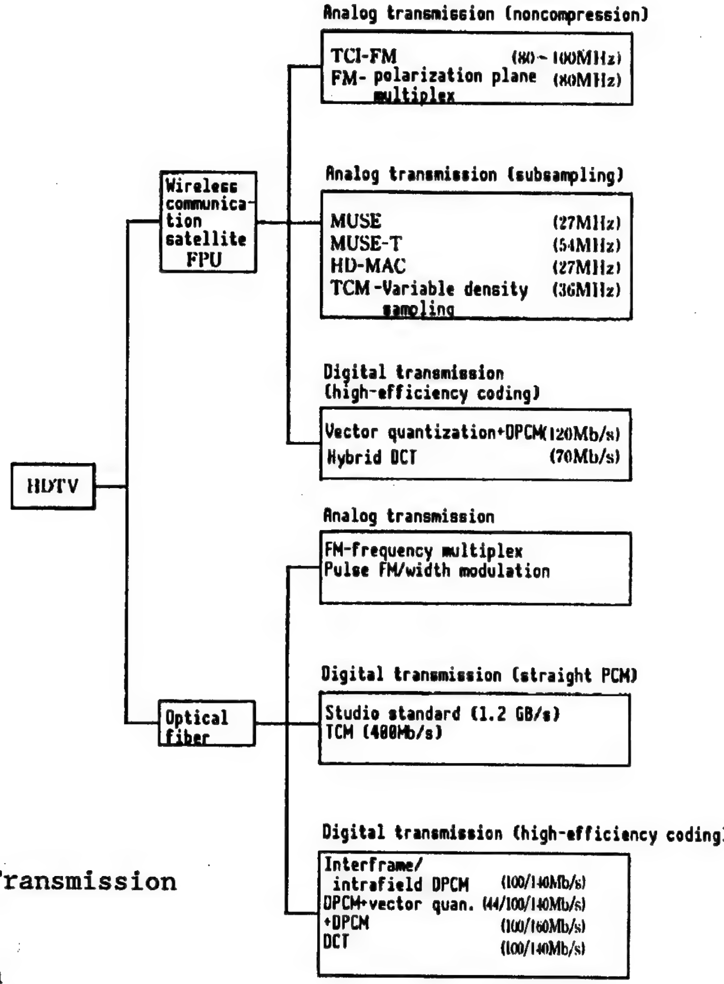


Figure 1. HDTV and Transmission System

3.1 TCI (TCM) System

Video signals include luminance signals and color signals and, as a system to multiplex signals that include aural signals into one transmission signal, there are time compressed integration (TCI) and time compression multiplexing (TCM). The two are exactly the same system.

Since the TCI system has no chrominance subcarrier in the high region and its spectrum can be regarded as a monochromatic signal, it can hardly be affected by the triangular noise spectrum of FM, and cross-color and cross-luminance interferences do not take place. At the same time, since it is resistive to nonlinear distortion of DG and DP, it can use a large emphasis gain by applying strong nonlinear emphasis. Therefore, the TCI system can be said to be suitable for FM transmission.

The two systems shown in Table 2 were manufactured on an experimental basis as a TCI system. Although both of them use digital sound, they differ in multiplexing. While system (1) implements the time division multiplex during the period of vertical blanking, system (2) adopts frequency multiplex by a

Table 2. Factors of TCI System

Item	System (1)	System (2)
Usage	FPU experimental station	Terrestrial broadcast experiment
Signal bandwidth (horizontal resolution)	Y: 24 MHz C: 8 MHz Line sequence	Y: 20 MHz C: 5 MHz Line sequence
Sound	Digital 2 ch or 4 ch	Digital 2 ch
Sound multiplex	Vertical blanking	Digital subcarrier
Baseband	30 MHz	26.2 MHz
RF frequency	42 GHz	23 GHz
RF band (FM)	80~100 MHz	82.4 MHz

digital subcarrier (QPSK). System (1) was used in a transmission experiment as an experimental station of FPU using a 42 GHz carrier frequency and was also often used for relaying HDTV broadcasting, and system (2) was used in terrestrial broadcasting experiments using 23 GHz carrier frequency to assess diffraction by buildings, the effect of multipath and an atmospheric propagation characteristic.

3.2 MUSE and HD-MAC

The Japanese MUSE system and the European HD-MAC system were developed for the purpose of broadcasting HDTV through one channel of a broadcasting satellite. Comparison of their factors and systems are shown in Table 3. Both systems carry out bandwidth compression by three-dimensional subsampling on the basis of TCI.

The important basic technology of both MUSE and HD-MAC is the analog transmission of sampled values. The analog transmission of sampled values is, in a way, the digital transmission of multiple values, since digital values converted into analog values by the encoder are converted back into digital values by the decoder without mutual interference. This is well-known technology used for transmitting digital bit streams. However, there is no precedent for using it for a signal of multiple values and a broadband like a video signal, and it was introduced for the first time in the development of MUSE.

A big difference between MUSE and HD-MAC lies in the subsampling mode and the detection of motion. MUSE's subsampling mode comes in two kinds, static and dynamic modes, and signals processed by these modes, respectively, are properly mixed in 16 stages through motion detection. Motion detection is

Table 3. Comparison of MUSE and HD-MAC

Factor	MUSE	HD-MAC
Sampling frequency	Y: 44.55 MHz C: 14.85 MHz	Y: 54 MHz C: 27 MHz
Color signal line sequence	Yes	Yes
Signal bandwidth (horizontal resolution)	Y: 20 MHz C: 7 MHz	Y: 23 MHz C: 11.5 MHz
Subsampling ratio	Y: 3:1 C: 4:1	Y: 4:1 C: 4:1
Transmission of sampled value	Yes	Yes
Motion mode	Static/dynamic modes Mixture in 16 stages	20, 40, 80 ms selection of three modes
Detection of motion	Detection by both encoder and decoder of every picture element	Detects by encoder and transmits every block of 8 x 8 to decoder
Motion vector	Panning and tilting only	Every 16 x 16
Sound multiplex	Vertical blanking	Horizontal blanking
Base	8.1 MHz	10.125 MHz
RF band (FM)	27 MHz	27 MHz
Compatibility with current TV	By converter	Compatible?

performed by both the encoder and decoder. On the other hand, HD-MAC has three modes, a mode applicable to slow motion in addition to the static and dynamic modes; it performs motion detection only by the encoder side to simplify the reception side's processing of static and dynamic motions; and it transmits signals to the decoder every block of 8 x 8. This system is called digitally assisted TV (DATV).

The MUSE system is incompatible with current TV. However, a simple down converter that converts from MUSE to TV's 525 scanning lines, was developed, so HDTV broadcasting can be received by a current TV set by using the converter.

On the other hand, HD-MAC is incompatible with PAL, European standard TV, but is with DC-MAC being proposed as a European satellite broadcasting system. However, if an HD-MAC signal is received by a D2-MAC receiver, folded distortion develops due to the failure of the interpolation of subsampling. Also, their aspect ratios are different, so that their compatibility is somewhat questionable. The same converter that MUSE uses may be needed to ensure high-quality pictures.

In regard to the present status of MUSE development, all LSIs for the receiver have been developed, and the experimental manufacture of a decoder using LSI has been completed. On the other hand, for HD-MAC development, ICs have been customized in part, so that miniaturization of the device is making progress. The development of LSI is still under way.

3.3 Analog Modulation System

The analog modulation system, which eliminates the need for digital signal processing such as time-based companding, has a characteristic that the device can be made very compact. This section will introduce some analog modulation systems whose hardware manufacture on an experimental basis has been reported as complete.

(1) Frequency Multiplex-Optical Transmission System

Optical fiber that is not restricted by band, not affected by electromagnetic noise, and capable of transmitting over a long distance of more than 20 km, is one of the powerful transmission media. A device for frequency multiplex (FM) optical transmission that modulates the frequency of digital audio, Y, Pb, and Pr signals and multiplexes by frequency allocation, as shown in Figure 2, was manufactured on an experimental basis as a frequency multiplex system using optical fiber.

This device was used for transmission between the Olympic stadium and the INTELSAT earth station for the rebroadcasting of the Seoul Olympic Games. HDTV signals received by the INTELSAT earth station were converted into MUSE signals, transmitted via INTELSAT to Japan, and broadcast.

(2) PFWM Optical Transmission System

Although FM is mostly used to modulate TV signals, a modulation system called pulse frequency and width modulation (PFWM), a combination of FM and pulse width modulation, was developed as an HDTV optical transmission system. In this system, for Y, the rise of a carrier wave is processed by pulse FM modulation (PFM), and for Pb and Pr, the fall of the signal processed by PFM is processed by pulse width modulation (PWM) in the sequence of pulses as shown in Figure 3. This device was used in the International Flower and Greenery Fair.

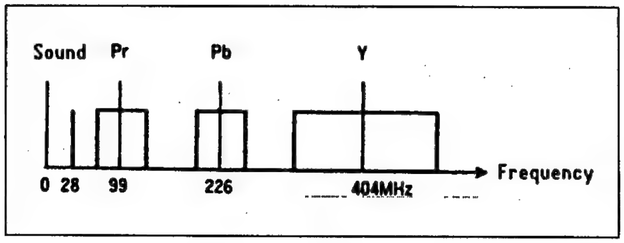


Figure 2. FM–Frequency Allocation of Frequency Multiplex Optical Transmission System

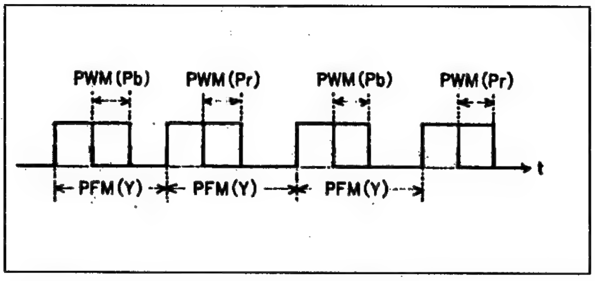


Figure 3. Waveform of PFWM

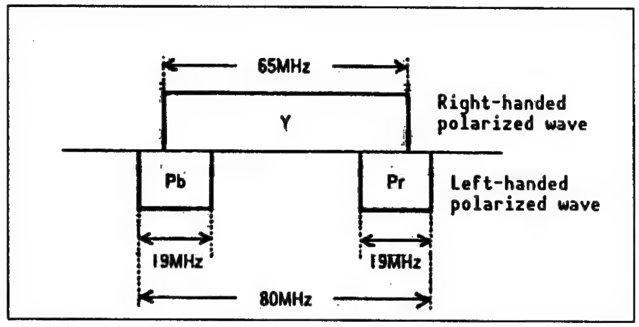


Figure 4. Frequency Allocation of FPU for Wireless Camera

(3) FM-Polarization Plane Multiplex System

HDTV broadcast programs are on the increase toward the commercialization plan of HDTV broadcast employing BS–3. In this connection, it is desired to make TV cameras more compact and efficient, to improve their mobility in order to collect materials at any place without restriction, and to expand the scope of material for TV programs.

For this purpose, development of a compact FPU of 42 GHz, aimed at introducing a wireless HDTV camera, is now under way. The FPU's characteristic is the multiplex of the plane of polarization. As shown in Figure 4, Pb and Pr signals are multiplexed after changing the planes of polarization at the band edges on both sides of the Y signal.

The hardware of this device was manufactured on an experimental basis, and its performance, including crosstalk, is being evaluated through field tests.

3.4 Digital Transmission of Component Signals

The transmission of TCM signals of 20 MHz at 400 Mb/s using Japan's F–400 M circuit at Tsukuba International Fair in 1985 was the first digital transmission of HDTV.

Table 4. Optical Transmission System of Studio Standards

Item	System (1)	System (2)	System (3)
Sampling	Y/Pb/Pr:74.25/37.125/37.125 MHz, 8 bit		
Signal band	Y/Pb/Pr: 30/15/15 MHz		
Source rate	1.188 Gb/s		
Modulation system	Binary RZ	Binary RZ	Ternary PST
Luminous element	GaAlAs-LD	DFB-LD	DFB-LD
Wavelength	0.77 μm	1.3 μm	1.3 μm
Fiber	GI	SM	SM
Light receiving element	Si-APD	Ternary PIN-PD	InGaAs-APD
Transmission distance	1 km	20 km	40 km

Some optical transmission systems with the sampling frequency of the studio standard were developed making use of the broadband of optical fiber. Typical systems are shown in Table 4.

System (1) was developed to connect digital devices of studios such as digital VTR for short-distance transmission, using inexpensive GI fiber. Systems (2) and (3) are aimed at long-distance transmission, using SM fiber, and both multiplex digital sound. For clock reproduction, system (2) employs the scramble system, and system (3) uses a three-value PST code whose level is certain to make transition per time slot. For word synchronization, system (2) adds the frame synchronization of 1 bit per 36 bits, and system (3) employs the rule violation system infringing the rules of PST codes.

3.5 Digital Transmission by High-Efficiency Coding

The sample frequency of Y and C specified in the HDTV Studio Standards are 74.25 MHz and 37.125 MHz, respectively, and if they are quantized by 8 bits, their source rates will exceed 1 Gb/s. It can be thought of to use such high bit-rate transmission in short-distance transmission through a private circuit, but it is uneconomical in terms of transmission cost to use for long-distance transmission using broadband ISDN. Therefore, it is advisable to reduce the bit rate by high-efficiency coding.

Bit rate reduction systems by high-efficiency coding were developed as shown in Table 5.

Table 5. HDTV High-Efficiency Coding System

	Band compression system	Bit rate	Sampling frequency
System (1)	Applies DPCM and divides into two groups of picture elements, G1 and G2 G1: Applies interframe forecasting /intrafield forecasting G2: Applies interframe forecasting /interpolation forecasting from G1	100/140 Mb/s	Y: 44.55 MHz C: 14.85 MHz
System (2)	Subsampling Former picture element forecast DPCM Fixed length code (4 bits)	120/140 Mb/s	Y: 48.6 MHz C: 16.2 MHz
System (3)	Subsampling Former picture element forecast DPCM Variable length code	100/160 Mb/s	Y: 44.55 MHz C: 14.85 MHz
System (4)	Low region: Intrafield direct/ frame forecasting DCT High region: Intrafield direct DCT (Compatible with present TV as long as reception is made in low region only.)	100/140 Mb/s	Y: 44.55 MHz C: 14.85 MHz
System (5)	Intrafield direct/field forecasting/motion correction frame forecasting DCT (Hybrid DCT)	70 Mb/s	Y: 54 MHz C: 27 MHz

System (1) divides HD signals line quincuncially into two groups of picture elements (G1 and G2). The G1 applies intrafield forecasting/interframe forecasting DPCM, and the G2 applies interpolation forecasting from G1 and interframe forecasting. With respect to its transmission experiments, when the Olympic Games were held in Seoul, an open transmission experiment using optical fiber between Ginza and Tokyo Station was carried out. Another transmission experiment was carried out between the site for the International Flower and Greenery Fair in Osaka and Tokyo.

System (2) is the DCPM method using line quincunx sampling, former value forecasting, and fixed length words, and was developed to transmit via the 72 MHz transponder of an INTELSAT satellite. This system succeeded in a satellite

transmission experiment between Japan and the United States, using an INTELSAT satellite. In addition, a half-inch digital data recorder (VTR) using this system was also developed.

System (3) is a system whose bit rate is reduced to 100 Mb/s by applying variable length codes to system (2), and its transmission experiments at fixed and variable speeds by ATM were carried out.

System (4), which was announced lately, applies DCT of 8 x 8 to input signals, of which a low region of 4 x 4 is coded by intrafield direct/interframe forecasting the remaining high region component is coded directly. This system is designed so as to ensure compatibility with current TV through the reception of low region components only.

System (5), which is being developed in Europe under the EUREKA 256 plan, uses intrafield direct/field forecasting/motion-corrected frame forecasting, and adopts DCT of 8 x 8 for coding. This system can make switching between 1250/50 and 1125/60 and its bit rate is 70 Mb/s. The system's ICs were mostly customized and the device's scale is very small (frontal size: about 45 x 25 cm). Its experimental transmission was carried out in the open demonstration show, using the Olympus satellite at the world soccer games held in June 1990.

4. Closing Remarks

The trends for standardizing HDTV studio standards and HDTV transmission devices whose hardware was experimentally manufactured, have been introduced above.

The present transmission devices mostly use analog technology, because analog is more advantageous in terms of device miniaturization and the bands used. On the other hand, the digital transmission system is more advantageous in terms of miniaturization, provided that LSI is introduced; it is expected to take the place of the analog transmission system as broadband ISDN spreads. In any event, miniaturization of devices through the introduction of LSI is necessary, and to this end it is important to establish coding systems and international standards.

HDTV, TV Camera Development

916C1008C Tokyo OPTRONICS in Japanese Oct 90 pp 63-68

[Article by Masayo Oka, Ikegami Tsushinki Co., Ltd.]

[Text] 1. **HDTV**

Since explanations of the standards of HDTV are expected to be given in other articles of this magazine, this article will give a brief description of how HDTV and HDTV cameras came to be developed.

In 1964, when development of current TV technology was completed, NHK Science and Technical Research Laboratories began looking for development themes concerning the "next-generation TV technology." Two themes, "stereoscopic television" and "high-quality television," were examined then, and "high-quality television" (later called HDTV) was finally adopted as a theme after considering their technical feasibility and the target dates for putting them into practical use.

At that time, the movie industry changed the standard system—a picture frame ratio 5:4—for a widescreen that would produce a deeper feeling of presence, and thus spur the revitalization of the motion picture market. Following this, pursuit of technology for high quality TV with real ambience and wider screens began.

According to the recollection of Takashi Fujio, ex-director of NHK Science and Technical Research Laboratories and one of the real inventors of HDTV technology, it was large-scale research involving digging broadly into basic problems, including the psychological effect of the feeling of presence and review of the foundation of the current NTSC system.

The current NTSC conducted extensive inquiries—from psychological and psychophysical studies on the visual system to the theory of color vision to communication systems—and solved the matter of compatibility with black-and-white TV broadcasting. These efforts are famous in technical history as an instance of a very energetic and skillful approach to development. Likewise, the efforts made to elaborately dig into and solve basic problems on HDTV will remain in development history, from which even engineers not specialized in broadcasting can gain a great deal of enlightenment.

Since broadcasting is the main object of HDTV technology, one is liable to be concerned only about high quality and high definition pictorial images. However, since this is misleading, I would like to call the attention of those who know little of broadcasting technology to some points, although they concern primitive problems.

Since HDTV strictly pursued high definition pictures worth viewers' appreciation of TV broadcast, it harmonizes with people's visual system. It also provided the best solutions to questions concerning broadcasting under some restrictive conditions, but not necessarily the best solutions from a physical viewpoint. To sum up this somewhat difficult-to-understand expression, attention is called to HDTV not trying to reproduce a subject image with physically high fidelity and definition.

For instance, the perpendicular resolution and horizontal resolution were set in consideration of the optimum balance for broadcasting. On the discovery through experiments that infinitely enhanced resolution does not necessarily proportionally improve picture quality, due to men's visual characteristics, and there is an optimum value, basic conditions were set for designing an HDTV system. Therefore, improving picture quality by picking up an object by finer video information and processing it through image processing, then measuring the picture parameters and image recognition, but disregarding the system of perception, can be said to be incorrect, depending on application.

Unless one keeps this in mind, he will encounter problems in its application to other areas.

2. HDTV Camera

2.1 Moving Picture Camera

Table 1 shows an example of the specifications for HDTV cameras. However, a camera as an article of trade cannot be manufactured based on them alone. For commercializing cameras it is necessary to meet various pickup requirements in regard to "structure," "picture quality," and "usability." This section will outline questions concerning "picture quality."

Table 1. Example of High Definition Camera's Specifications

Camera tube	1 inch Saticon MS type
Resolution	40% (800 TV lines)
Signal to noise (S/N) ratio	46 dB
Sensitivity	F2.8 (2000 lux)
Afterimage	Below 1 percent
Maximum length of cable	(Optical fiber)

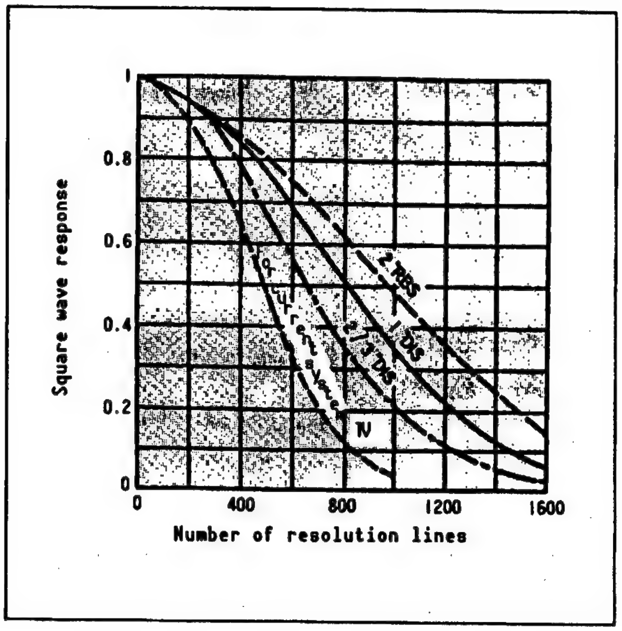


Figure 1. Resolution Characteristics of Various Camera Tubes

As mentioned above, "picture quality" is defined as the evaluation by viewers when appreciating televised programs. Generally, the elements determining the "picture quality" of TV cameras are "resolution," "sensitivity," "S/N ratio," and "registration." They are contrary to each other, and the optimum combination of them, that is, the trade-off, is the object of designers' efforts. Brief explanations of them will be given in the following.

(1) Resolution

A TV camera forms an image through the optical lenses in its three tubes by the tri-color separation system, and the first priority was given to these camera tubes in HDTV development.

More specifically, it was necessary to ensure high resolution by improving the photoelectric conversion section of a camera tube. Generally, it is thought to make a photoelectric conversion target thinner to improve resolution, but this is incorrect because it leads to lower sensitivity and increased afterimage. Therefore, the question was how to develop a photoelectric conversion section of high resolving power that showed no afterimage or lower sensitivity.

Figure 1 shows the resolution characteristics of the camera tube of the existing NTSC system and HDTV camera tubes of three kinds measured by NHK Science and Technical Research Laboratories.

Meantime, resolution characteristics are discussed in reference to the relationship between the space frequency characteristics of the conversion system and signal modulation factor (amplitude response). The specifications of a conventional camera show "threshold resolution," which is a discrimination limit determined by the eye on a monitor displaying an imaged chart of standard resolution measurements.

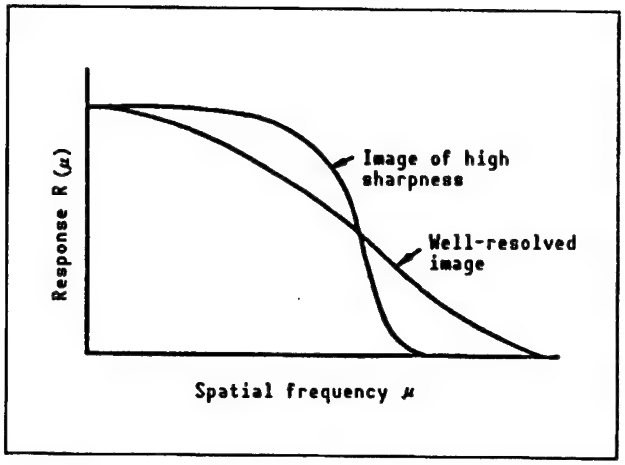


Figure 2. Pictorial Image and Amplitude Characteristics

However, useful parameters in image processing are amplitude modulation factors, and the form of characteristics curves. As shown in Figure 2, a desirable curve changes, depending on how to handle the object's video information.

Generally, when designing a camera, the output signal of its camera tube targets "a response of about 40 percent in the horizontal resolution of 870 TV lines." Since, however, the characteristics of the camera tube do not fill it, image enhancement is applied in a high area. However, if the camera tube's reading current is intensified, resolution will decline, due to the relationship between a scanning beam diameter and current density, so resolution and a signal's output level (relates to S/N ratio) are contrary to each other.

In addition, resolution characteristics of the optical system are also important, because visual characteristics indicate that if the F-number of a lens is below 2.8, resolution will deteriorate sharply.

(2) Sensitivity

It is intended for HDTV to increase the depth of field to ensure high picture quality as well as high resolving power in an attempt to improve the feeling of presence. However, if an HDTV camera tube's diameter equals that of the current NTSC system camera, the effective space of one picture element's area becomes small compared with the current system, resulting in declined sensitivity.

Therefore, to prevent the fall of sensitivity, various methods can be devised, such as making lenses brighter, decreasing loss in the optical system, and enlarging the plane of the camera tube. However, since HDTV camera's average sensitivity is very low, compared with the current NTSC system camera, despite such devices, it is necessary to open the iris of the lens system. Consequently, the depth of field will become shallow, making focusing difficult. In such a case, a pictorial image will not be well in focus, making HDTV nonsense after all. Therefore, enhancement of the camera tube's sensitivity became absolutely necessary.

The recent development of a high sensitivity tube using avalanche multiplication for improving sensitivity is one of the results produced by NHK Science and Technical Research Laboratories. Thanks to this development, the HDTV camera became able to take pictures under the same illuminating conditions as the current NTSC system and to do so more practically.

(3) S/N Ratio

The S/N ratio is a design value regarded as an important parameter for comparing the performance of cameras, and constant efforts are being made to improve the S/N ratio for cameras of the current system. Since the HDTV system handles signals from a broader frequency band (30 MHz, where NTSC system's video signal is 4.2 MHz), ensuring a desired S/N ratio will become a more difficult development.

Because, generally, as frequency becomes greater, the S/N ratio deteriorates. This is a dominant factor of deterioration of signal to noise. Since a camera tube's output is of a very small level, several 100 nA, it is amplified to a required video signal level by a preamplifier, but the noise of the amplifier is "triangular noise" that grows stronger in proportion to frequency. This is an exemplary deterioration factor.

Even if the noise components of spatial frequency in a high area are not felt by the eye because of the nature of the visual system having a "low-pass filter" type characteristic, it is still necessary to improve the S/N ratio. Therefore, development of the amplifier's circuit elements themselves is also included in development programs. Please refer to technical books for details.

(4) Registration

"Registration" is a design parameter important to a color camera's color reproducibility. Briefly, deviation of registration means deviation from theoretical values concerning scanning positions and timing in three camera tubes, R, G, and B. If registration characteristics are unsatisfactory, "color slippage" and "color fading" will develop. In particular, "color slippage" is an element that gives viewers the most unpleasant feeling when appreciating color pictures.

The relationship between the deviation of "registration" and the resolution of luminance signals is shown in Figure 3. It indicates that despite satisfactory resolution characteristics, worsening registration leads to deterioration of resolution of the entire system.

In terms of digital image processing, premeasurement of the volume of deviation from the specified position by dividing the area of the image makes it possible to easily correct it geometrically. However, because of TV techniques, it is not so easy to implement, because it is absolutely necessary to complete corrective operations within a specified time (scanning time per field).

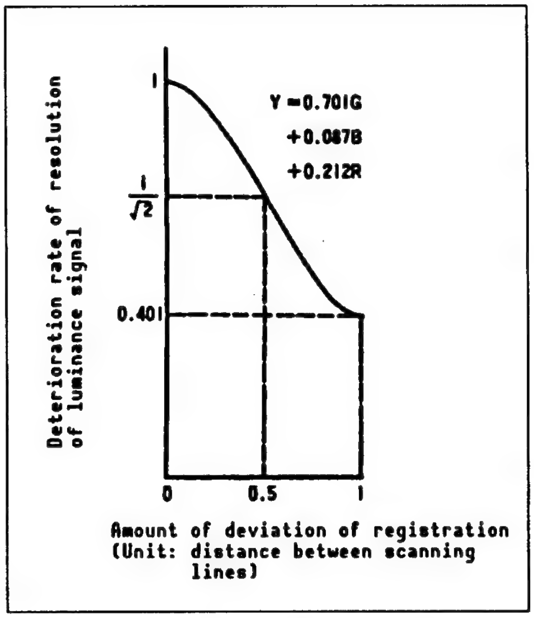


Figure 3. Deterioration of Resolution Due to Deviation of Registration

Additionally, since the state of deviation of "registration" depends on fluctuations in temperature, earth magnetism, and the zoom lens' focal length—that is, its conditions are not fixed—it is necessary to use some contrivance in designing.

Technical points of motion picture cameras have been outlined above. The specifications of our company's products are shown in Table 2 for your information.

2.2 Still Picture Camera

When preparing HDTV programs, it is sometimes necessary to take pictures of materials such as copy. Therefore, still picture cameras for transparent copies (mostly camera films) and reflective copies are developed.

Since still pictures must be of high quality, compared with motion pictures, the existing motion picture camera tubes for HDTV are unsatisfactory in terms of characteristics. In this connection, main technical points will be enumerated as follows, based on our experience in development.

(1) Advantages of Still Picture Input Device in Designing

Although still picture input is restricted by the time required for preparing TV programs in terms of efficiency, a dozens of seconds spent to take a picture do not matter. This moderate time restriction allows a freedom that motion picture cameras cannot enjoy for image operation functions and system designing.

Table 2. Motion Picture Camera

	Ikegami Tsushinki HDS-71 1984	Ikegami Tsushinki EC-1125 1987
Rating		
Type	Standard	Portable
Composition	Head, CCU	Head, CCU
Camera tube	Saticon, 1" MS type	Plumbicon, 1¼ MS type
Contour compensator	Analog system Out of green	Digital delay line Three contours
External dimensions W x H x D (mm)	Head 277 x 460 x 480 CCU 428 x 442 x 398	Head 164 x 405 x 300 CCU 260 x 920 x 450 (contour corrector included)
Cable	Multicore cable (44.5 kg/100 m) 200 m Optical fiber (13 kg/100 m) 1 km	Multicore cable (36.5 kg/100 m) 275 m Optical fiber (16 kg/100 m) 1.5 km
Weight	Head 39 kg, CCU 58 kg	Head 17 kg, CCU 85 kg
Power supply	AC 100 V	AC 100 V
Power consumption	400 W	160 W, contour corrector 210 W
Lens	14-power zoom lens (12.5~175) F1.6	14-power zoom lens (16.5~231) 5-power zoom lens (16~80) Fixed focus: 5 kinds F1.4
Capacity		
Electric current of signal	0.4 μA	0.35 μA
Sensitivity	2000 lux F2.8 + ½	2000 lux F5.6
Signal band	Main body 30 MHz~0.5 dB Contour compensator 30 MHz~3 dB	Main body 30 MHz~0.5 dB Contour compensator 30 MHz~3 dB
S/N ratio	44 dB	47 dB
Resolution	35%	35%
Registration	0.25% (First zone) 0.05% (Others)	0.03% (0.9 H.V) 0.045% (Others)

The specifications of a still picture camera are shown in Table 3, in which its functions are indicated in the column of a "digital processing system."

Compared with the characteristics of motion picture cameras, still picture cameras have many advantages. In regard to the "resolution," for example, the still picture camera can input signals with ample resolving power at the pickup section and convert them at the final output section in conformity with

Table 3. Still Picture Camera
(Ikegami Tsushinki HSC-1000 "High Definition Still Camera" 1987)

(1) Basic capacity

1. Number of picture elements in effective picture area	Horizontal 1,920 x perpendicular 1,035
2. Aspect ratio	16:9
3. Reading time	About 30 s
4. Monitoring system	
• Number of scanning lines	1,125
• Field frequency	60 Hz
• Signal band	30 MHz
• Synchronizing signal	Ternary synchronizing system

(2) Rating

1. Stage	
• Form size	Reflective copy A3 (420 x 297 mm)~ A6 (148 x 105 mm)~ 6 x 6 size (60 x 60 mm) Transparent copy 8" x 10" (254 x 203 mm) ~ 35 mm
• Kind of copy	Reflective and transparent
• Mechanism	Motor-driven transfer X ± 105 mm Y ± 75 mm θ ± 5°
• Illumination	Reflective and penetrable illumination
2. Lens system • Setting of angle of view	Size and focus adjustment (A3, A4, A5, A6, 8" x 10," 6 x 6.35 mm)
3. Imaging system	
• Imaging system	CCD line sensor imaging Color filter switching mechanism
• Scanning system	Horizontal: by line sensor Perpendicular: by mechanical scanning
• Resolving power	Horizontal: 1,920 Perpendicular: 1,035
• Auxiliary imaging system	Monochromatic area sensor camera (480 x 345)→(1,920 x 1,035) (Horizontal 4 times, vertical 3 times)
4. Analog processing system • Correction of white uniformity • Correction of shading • Automatic white balancing • γ coarse tone (γ = 1 (Off), 0.55, 0.45, 0.35, 0.22)	

[continued]

[Continuation of Table 3]

5. Digital processing system		
• Dynamic range:	150% (10 bits)	
• Color correction	(1) Gain:	R,G,B ±30%
	(2) Color difference gain:	R-Y, G-Y ±30% B-Y, master
	(3) γ:	R,G,B, ± 20%
	(4) Black γ:	Three kinds
	(5) Pedestal:	R,G,B, master + 15~30%
	(6) Knee slope:	Master Knee point 70~100% Slope 1~1/6
	(7) White clip:	Master 90~120%
• Contour correction	Perpendicular 3 taps, horizontal 5 taps	
	Booster frequency	Select 1 from 3 kinds (19, 22, 25 MHz)
	Adjustment item	(1) Detail gain (2) Detail threshold
	Noise reduction	Reducing noise by repeating scanning

"HDTV signal standards." Also, in regard to the sensitivity and "S/N ratio," since it is sufficient for the still picture camera to consider raising levels of signals as much as possible, the quantity of light (the intensity of the light source for illumination) can be increased insofar as the copy is not affected. Also, in regard to signal processing circuits, the extension of scanning cycles eliminates the need for a broadband and high-speed operation system. Additionally, in regard to the "registration," although mechanical precision must be assured, the still picture camera is advantageous theoretically, if the camera tube is not used. Furthermore, if separation of the three primary colors can be done by sequential reading, the still picture camera will be released from the burdensome optical designing and processing work, and the question of color slippage will be solved.

Therefore, compared with the motion picture camera that must complete all kinds of processing within a specified scanning time, the still picture camera can develop all design items with time on hand, making it possible to pursue high performance and high functions.

(2) Pickup System

A system that obtains a two-dimensional pictorial image by driving a one-dimensional CCD sensor by a mechanical system, was adopted. It has the advantage of using a cheap solid-state pickup element of high resolving power.

The solid-state pickup element cannot be free from dispersed characteristics of each element (each signal conversion element section). Although it is expected to be gradually improved by the advance of manufacturing technology, it has not been accomplished at all to date. So, there is no alternative but to contrive a correction circuit or use the solid-state pickup element with patience. Since the two-dimensional sensor consequently requires a tremendous number of elements, compared with a one-dimensional sensor, correction is difficult to make. For brevity, if horizontal and perpendicular resolving power represent 2,000 picture elements and 1,000 lines, respectively, for example, the one-dimensional sensor is satisfied with 3,000 picture elements, while the two-dimensional sensor needs 2 million picture elements. Therefore, the effect of nonuniformity of an element is far-reaching.

In regard to color separation, the application of tri-color simultaneous separation optics was once examined at the beginning of development, setting horizontal image resolving power at 1,920 picture elements, but it was determined to be difficult to realize in view of "optical astigmatism," "the mounting accuracy of CCD elements," and "the overall accuracy of the driving system." Therefore, sequential separation optics, which can be developed with certainty, were adopted, although reading time is long. In other words, a system that scans the same copy three times while switching three color filters consecutively, was adopted.

Meanwhile, in regard to the dispersion of the one-dimensional element, the corrective operation of each element was carried out automatically when initializing the system.

(3) Digital Processing

The moderate time restrictions on digital signal processing allow the frequent use of two-dimensional processing. To be more precise, the motion picture camera basically processes time series video signals, obtained by scanning the surface of the object, by the picture processing circuit while maintaining the waiting time of the time series. When the signals are picked up as still pictures, they can be freely processed after storing them in the frame memory after a stroke of scanning, by handling necessary processing and technique as a random memory. For processing, it is possible to employ any method developed for picture processing or image processing. It is, therefore, convenient to improve picture quality.

Since the still picture camera is used exclusively for preparing TV broadcast programs, correction of transformation was elaborately accomplished to improve the characteristics of video signals.

3. Application of HDTV Technology

When I remember that the existing NTSC system, based on the technological level of 40 years ago, has been in force for so long a period, I again have great regard for the pioneer-like researchers' right aims and design concepts at that time. On the other hand, however, there might be an impression that now is about the time when there should be an updating of the system.

Apart from whether or not HDTV technology likewise has the foresight that finds a place in a 40-year history, it certainly meets the requirements of the times.

Since HDTV technology is said to have the possibility of wide usage besides broadcasting, let me verify it.

First, media converted into electronic information are incomparably advantageous as information material. If HDTV technology is employed in movie production, it will allow confirmation of the results of a shoot right on the spot, without developing the film, and can make use of various image processing techniques for editing.

Also, if the tremendous quantity of letters and video information accumulated by publishing circles can all be converted into electronic information, various publications can be produced from one material data base through a variety of editing and processing. Therefore, new ventures typical of the knowledge- and information-oriented society can be anticipated. The present level of HDTV technology is not high enough to ensure picture quality worth printing, but it will offer a basis for the growth of such printing technology in the future.

The application of HDTV technology to areas other than broadcasting was shown roughly above. However, it may be necessary to confirm anew the importance of the camera, which is the gateway to the "HDTV system."

HDTV Single-Chip CCD Color Camera

916C1008D Tokyo OPTRONICS in Japanese Oct 90 pp 73-78

[Article by Takanori Tanaka, Microelectronics Research Laboratories, NEC Corporation]

[Text] **1. Introduction**

Since HDTV, characteristics by a high aspect ratio, large screen, and high resolution, is expected to be widely applied as a next-generation medium to such areas as TV broadcasting, movie production, and printing, the development of its related technologies is making rapid progress. In the area of cameras, high-definition solid-state image elements (high-definition CCD image elements) and three-chip color cameras adaptable to HDTV have reportedly been developed already. Since HDTV is aimed at high resolution and high picture quality, the main object of research and development to date has been a three-chip camera. However, development of a compact, light, and inexpensive single-chip HDTV camera for home use is a future task.

To separate the color signals from the object's image, the single-chip color camera gains different color light signals from each picture element, respectively, by using a color filter array in a mosaic structure placed against picture elements, so an image element with a greater number of picture elements is required. In regard to the present status of solid-state image elements for the standard TV, most home video cameras are using CCD image elements with 200,000-300,000 picture elements each, while broadcast studio cameras are using CCD image elements with about 400,000 picture elements in place of the camera tubes heretofore in use. On the other hand, the number of picture elements of a high definition CCD image element adaptable to HDTV reportedly totals two million. This number of picture elements is sufficient for the three-chip camera to ensure satisfactory performance, but not for the single-chip color camera. Therefore, to secure satisfactorily high resolution and picture quality for HDTV by the single-chip color camera, it is important to optimize color separation. Based on experimental manufacture by the author, et al., mention will be made in this article of the HDTV single-chip color camera using a high-definition CCD image element with two-million picture elements.

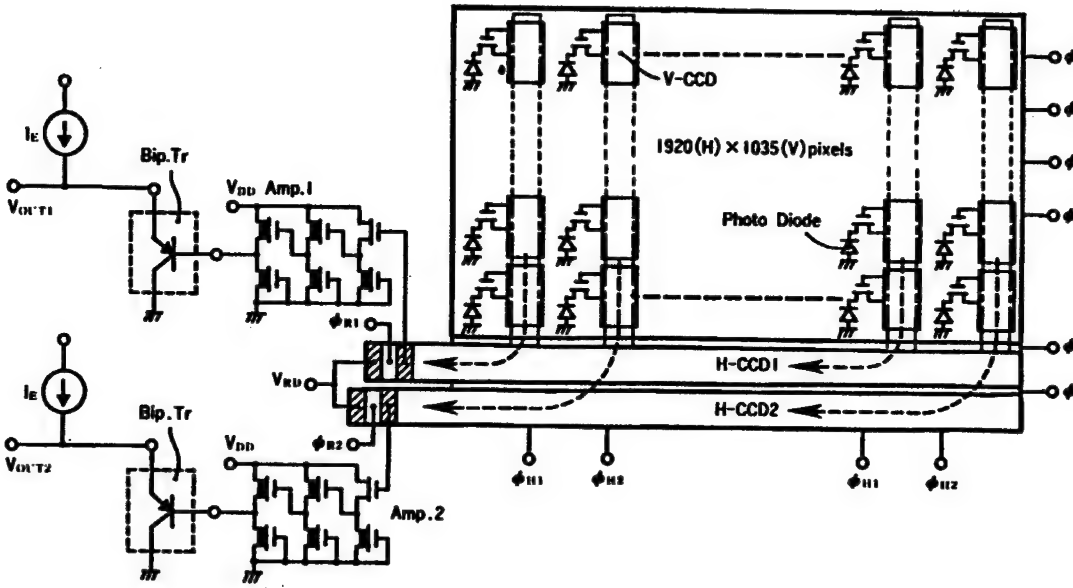


Figure 1. Construction of a Two-Million Picture Element High-Definition CCD Image Element

2. Two-Million Picture Element HD CCD Image Element

Figure 1 shows the construction of an HD CCD image element with two-million picture elements. This CCD image element has a one-inch optical format and interline transfer and conforms to the high-definition studio standards. Figure 2 shows these standards by means of picture consideration. The aspect ratio is 16:9, longer sideways than the standard TV's 4:3. The total number of scanning lines is 1,125 and the number of effective scanning lines 1,035, about two times the standard television. The CCD image element conforms to these standards, with 1,035 vertical effective picture elements and 1,920 horizontal effective picture elements. Also, it conforms to the digital sampling standards that specify the total number of horizontal samples as 2,200 points and the number of horizontal effective samples as 1,920 points.

The CCD image element adopts 2:1 interlaced scanning, the same as standard TV, and the frame frequency is 30 Hz. The horizontal data rate (sampling frequency) in image reading at 30 Hz/s is 74.25 MHz, about six times faster than the standard TV's CCD image element. The CCD image element employs the following technology to achieve such fast operation. First, a dual reading channel structure is introduced to its horizontal CCD register section. In this structure, two horizontal CCD registers (H-CCD 1, H-CCD 2) are placed in parallel on both sides of the transfer gate (ϕT); the signal charge from a vertical CCD register of an odd number in the horizontal direction is sent to the upper horizontal CCD register (H-CCD 1); the signal charge from a vertical CCD register of an even number is sent to the lower horizontal CCD register (H-CCD 2) via the transfer gate; and then horizontal transfer is carried out. As a result, the driving frequency of the horizontal CCD registers can be reduced to 37.125 MHz, half the data rate, making driving easier.

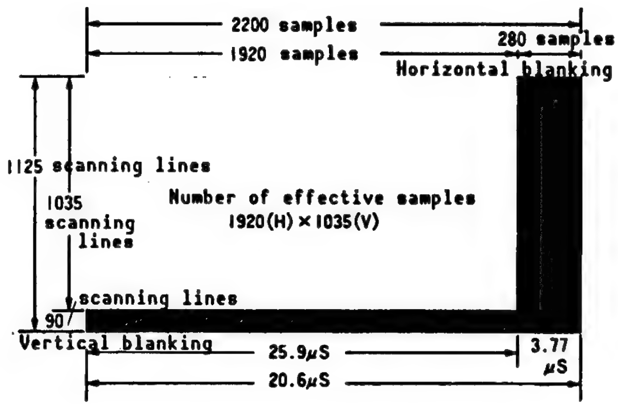


Figure 2. Screen Structure of HDTV Standard

Additionally, this method is used for dividing the bus lines of the horizontal CCD registers to reduce driving waveform distortion and drive them by respective drivers. Second, the structure of a three-stage source follower is introduced to the on-chip amplifier of the output section. Also, it achieves a broader band and lower noise by forming an output buffer circuit with bipolar transistors (Bip Tr) mounted in the same package of CCD to reduce the load capacity of the on-chip amplifier's final stage.

Table 1 shows the outline of the high-definition CCD image element.

Table 1. Outline of High-Definition CCD Image Element

Imaging system	Interline transfer
Tip size	16.5(H) x 10.0(V) mm
Effective imaging area	14.0(H) x 7.8(V) mm 1" optical format
Aspect ratio	16:9
No. of effective picture elements	1,920(H) x 1,035(V)
Size of picture element	7.3(H) x 7.6(V) μm
Driving system	Vertical CCD Four-phase drive BCCD Horizontal CCD Two-phase drive BCCD Dual channel transfer
Driving frequency	Vertical 33.75 kHz Horizontal 37.125 MHz x 2 (data rate 74.25 MHz)
Threshold resolution	Horizontal 1,000 TV lines Vertical 800 TV lines (field storage)

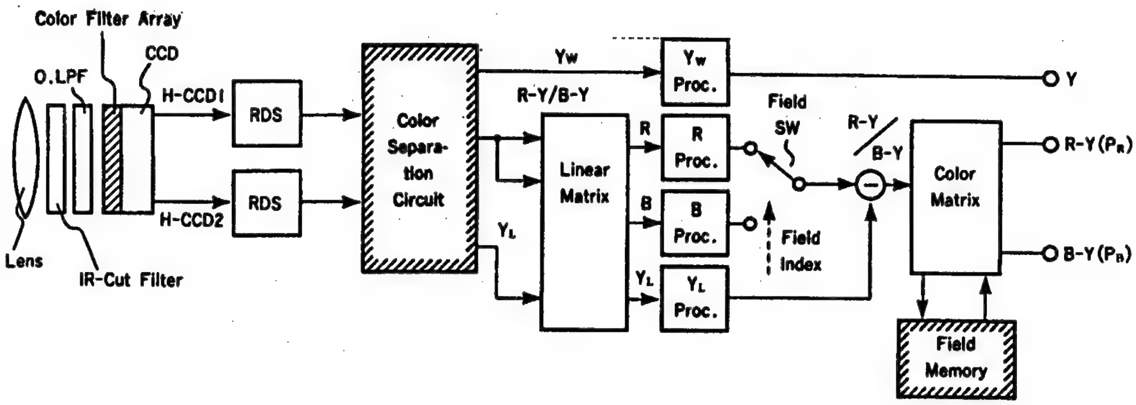


Figure 3. Systematic Diagram of HDTV Single-Chip CCD Color Camera

3. HDTV Single-Chip CCD Color Camera

Figure 3 shows a systematic diagram of the HDTV single-chip CCD color camera, and Photo 1 [not reproduced] its external view. The light condensed by the lens forms an image in the CCD image element after consecutively passing through the infrared-cut filter and optical low-pass filter (optical LPF), to optimize its spectral characteristics and MTF characteristics, and being separated into color light components by the color filter array, and then undergoes photo-electric conversion. The author, et al., proposed "color difference field sequential color separation" as a color signal separation method to produce high resolution and high picture quality for HDTV by the single-chip type camera. This new color separation method is to obtain two kinds of color difference signals in field sequence. Color filters are so arranged as to be able to gain R-Y signals in odd-numbered fields and B-Y signals in even-numbered fields. Thus, the horizontal sampling frequency of the color signals were made equal to that of the luminance signals to prevent the occurrence of color moire and false color signals, which cause deterioration of picture quality.

3.1 Color Difference Field Sequential Method

Figure 4 shows the arrangement of the color filter array and the principle of color separation. The color filter array consists of four color filters, magenta (Mg) of the complementary color group, green (G), yellow (Ye) and cyanogen (Cy). In the first line, MG and G filters are alternately arranged horizontally, and in the second line, Ye and Cy filters are arranged alternately. Also, these filters are arranged vertically at a phase angle of 180°.

In regard to signal reading from each picture element, the signal charge of the two vertically adjacent elements is combined inside the CCD and is output. Therefore, in No. n scanning line (No. n line) of the first field (1 F), signal (Mg + Ye)—a combination of vertically adjacent Mg and Ye—and signal (G + Cy)—a combination of G and Cy—are gained horizontally in sequence. On the other hand, in the No. n + 1 line, (G + Cy) and (Mg + Ye) are gained in the inverse order.

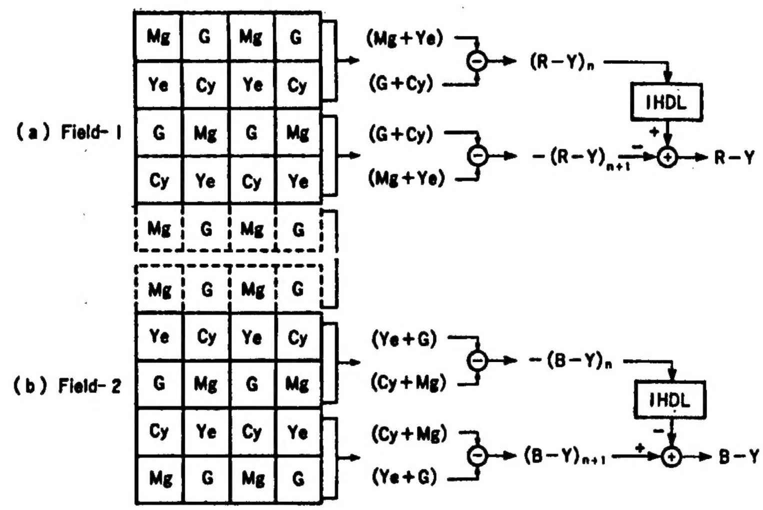


Figure 4. Arrangement of Color Filters and
Color Separation Method

In regard to luminance signals out of the CCD's output signals in respective lines, a luminance signal (Y) is obtained as the average value of the four picture elements Mg, G, Ye, and Cy, and the color difference signals (R-Y, B-Y signals) overlap the luminance signals of the baseband as a modulation component. The modulation components in respective lines can be shown by the following expressions:

$$n \text{ line } (Mg + Ye) - (G + Cy) = (R-Y)n \qquad (1)$$

$$n+1 \text{ line } (G + Cy) \quad (Mg + Ye) = -(R-Y)n+1 \qquad (2)$$

In the second field (2F), the combinations of picture elements formed inside the CCD differ vertically by one picture element each from those of the first field, due to interlaced scanning. Signals (Ye + G) and (Cy + Mg) in the n line are gained in the inverse order of the n+1 line. The modulation components of the second field can be shown in the following expressions:

$$n \text{ line } (Ye + G) - (Cy + Mg) = -(B-Y)n \qquad (3)$$

$$n+1 \text{ line } (Cy + Mg) - (Ye + G) = (B-Y)n+1 \qquad (4)$$

As shown in the four expressions, color difference signals R-Y in 1F and B-Y in 2F are gained from this color distribution. This is the color difference field sequential method. These color difference signals are available in both fields at the π phase of every scanning line, and the modulation frequency is equal to the Nyquist frequency (37.125 MHz) of a luminance signal.

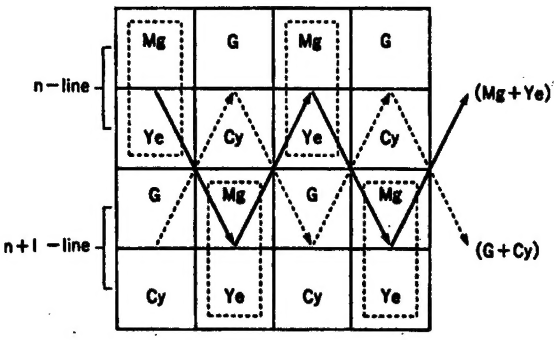


Figure 5. Interpolation of Sampling Points

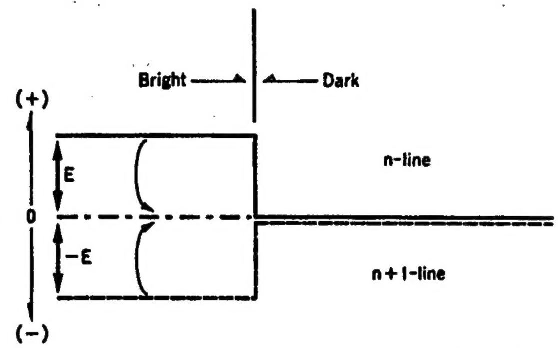


Figure 6(a). Prevention of False Color Signals

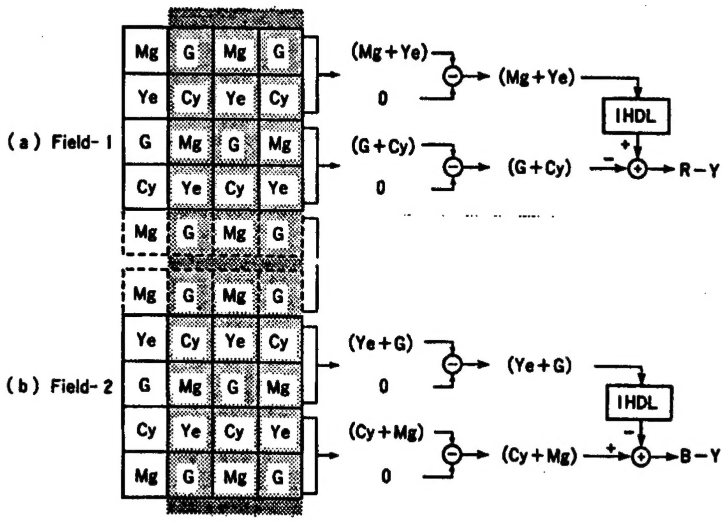


Figure 6(b). Prevention of Operational Errors

3.2 Separation of Color Signals

The separation of color difference signals is done in both fields by adding the modulation components of the n lines to the color difference signals of the n+1 line at opposite phases after delaying by one scanning interval (1H). The sampling points of the color difference signals in both n and n+1 line are interpolated in each scanning line by this operation. Figure 5 shows this interpolation taking the (Mg + Ye) signal for example. This signal is the sampling point of the (Mg + Ye) signal in an odd-numbered column in the n line. Therefore, both sampling points are interpolated by this adding operation. As a result, the (Mg + Ye) signal, whose horizontal sampling frequency is equal to the sampling frequency of a luminance signal, can be gained. This goes for (G + Cy) signal, too. From these two signals a color difference signal with the same horizontal resolution as a luminance signal can be gained. As a result, the folding distortion of color difference signal sampling does not develop.

Next, the contour section of an image (the netted section in Figure 6(a) generates a horizontal correlation error due to the lack of horizontal correlation. The operational error due to this leads to (G + Cy) = 0 in the n line, so the operation in expression (1) cannot be carried out and positive operational error E develops. This is shown in Figure 6(b). Since the existing standard TV single-chip color camera's color separation system separates one color difference signal from one scanning line's signal, this operational error E becomes a false color signal that deteriorates the picture quality. Since it is necessary to decrease the object's high spatial frequency components to prevent the operational error E, the optical LPF having an attenuation pole in the spatial frequency in the neighborhood of a color difference signal's Nyquist frequency is inserted in the optical path to shade off the object's image formed in the image element, causing the resolution to lower. However, under the color difference field sequential method, since (Mg + Ye) equals 0 in the n+1 line, a negative operational error -E is generated from expression (2). But since this operational error is opposite to the n line in polarity, it is offset by the adding operation between two scanning lines, as shown in Figure 6(b), and no horizontal correlation error is generated.

3.3 Construction of Video Signal Processing Circuit

The output signals from the two output amplifiers of the two-million picture element CCD image element are separated into the above-mentioned color signal, a broadband luminance signal (Y_W), and a low area luminance signal (Y_L) by the color separation circuit after improving the signal to noise (S/N) ratio by the RDS circuits controlling noise. The separated color signal is demodulated to R and B signals, as shown in the systematic diagram, by matrix processing to improve color reproducibility and given γ correction. Y_W and Y_L signals can be gained by just passing the CCD image element's output signal through the low-pass filter.

Next, since R-Y and B-Y signals can be gained in field sequence, the color difference signal made available is synchronized and converted into continuous signals. Synchronization forms a color difference signal of one-field delay in the digital field memory (capacity: about 300 kb) and switches alternately for every field.

4. Outline of Camera's Characteristics

An example of a picture taken by the single-chip color camera is shown in Photo 2 [not reproduced]. The camera realized high resolution and high picture quality as shown there by the new color difference field sequential color separation method and produced an excellent pictorial image, up to details without false color signals. The characteristics of this camera are shown in Table 2.

Table 2. Outline of camera's Characteristics

No. of scanning lines	1,125 lines
No. of effective scanning lines	1,035 lines
Field frequency	60.0 Hz
Scanning system	2:1 interlaced
Aspect ratio	16:9
Sensitivity	2,000 Lx, F4
S/N ratio	47 dB
Resolution	Horizontal 850 TV lines Vertical 800 TV lines

5. Conclusion

Mention was made above of the HDTV single-chip color camera using a two-million picture element HD CCD image element. To adapt the single-chip color camera to HDTV, characterized by high resolution and high picture quality, it is necessary to optimize the color separation method to prevent the occurrence of error signals in operation between picture elements for color signal separation. In addition, performance beyond the standard TV's is required for a color camera in regard to basic characteristics such as sensitivity, S/N ratio, dynamic range, and color reproducibility. However, since the solid state image element and the imaging method have much room for improvement, it is thought to be necessary to improve their characteristics in the future in order to put HDTV to practical use.

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